THE EFFECT OF BIOLOGICAL AND PHYSICAL FACTORS ON THE EARLY LIFE HISTORY AND SETTLEMENT OF THE TASMANIAN BLENNY *Parablennius tasmanianus tasmanianus* IN THE DERWENT ESTUARY, TASMANIA

by

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DECLARATION

I declared that this Thesis contains no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the Thesis, and to the best of the Candidate's knowledge and belief no material previously published or written by another person except where due acknowledgment is made in the text of the Thesis.

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ABSTRACT

THE EFFECT OF BIOLOGICAL AND PHYSICAL FACTORS ON THE EARLY LIFE HISTORY AND SETTLEMENT OF THE TASMANIAN BLENNY *Parablennius tasmanianus tasmanianus* IN THE DERWENT ESTUARY, TASMANIA

The effect of pulses in phytoplankton production (chlorophyll-a concentration) and physical factors on recruitment of the Tasmanian Blenny *Parablennius tasmanianus tasmanianus* was examined in the Derwent Estuary, Storm Bay, south-east Tasmania. The species is the only Tasmanian representative of the Family Blenniidae and is abundant in shallow reef habitats around Tasmania. Although the larvae are abundant around Tasmania and readily distinguished from those of other fish in plankton samples, it has been the subject of few scientific studies.

Pulses in chlorophyll-a concentration regularly occur in spring within the region, although the exact timing and magnitude vary interannually. To test the hypothesis that short-duration pulses in phytoplankton production translate into periods of high rates of larval survival and subsequent juvenile settlement, larval fish were sampled weekly from mid spring to late summer in 1992-93 and 1993-94, and newly settled blennies were collected biweekly from tide pools in a rock reef platform from mid spring to late summer in 1992-93, 1993-94, and 1994-95. Otolith analysis was used to determine larval durations and to back-calculate settlement patterns and hatching dates.

Blennies spent an average of 46 days in the plankton, and were on average 17.3 mm at settlement which did not appear to vary interannually ($P > 0.05$). Both larval abundance and settlement patterns differed markedly between years, with the highest settlement in 1994-95. However, there was no consistent relationship between the timing or magnitude of spring pulses in phytoplankton production and larval abundance, hatching times, or subsequent settlement.

An alternative hypothesis, that larval abundance and settlement were determined by physical factors, was examined by seeking correlation with surface water temperature, salinity, river discharge, rainfall, wind, tidal range and lunar phase. Water column data on these variables were collected during larval and phytoplankton sampling. No clear relationship

emerged between any environmental factor and hatching times or subsequent settlement, but peaks in larval abundance consistently correlated with high water temperatures and low salinities. Intensive sampling in different water masses confirmed that larvae were primarily distributed in water characterised by low or intermediate salinity (26 - 30‰) and were mostly found in warmer water (16.3°C - 17.9°C). The observations suggested that newly settled blennies were likely to be most abundant in the area with low salinity. To test this, surface water temperatures and salinities were measured every other day and newly settled blennies were collected biweekly from three sites characterised by different mean salinities. In contrast to expectations, the highest settlement occurred at the site with the highest mean salinity ($P < 0.05$). This suggests that the salinity preferences of newly settled blennies differ from those sampled in plankton tows, or that settlement at the site with the highest salinity was an artifact of other conditions that differed in tide pools between the three areas.

The results of this study suggest that hatching times, larval abundance, and settlement of the Tasmanian blenny were not strongly influenced by phytoplankton production pulses or most of the physical factors assessed. Salinity and temperature appeared to affect the abundance of planktonic larvae. This relationship became less clear at settlement. It is suggested that hatching time of the Tasmanian blenny is regulated by simple environmental cues such as photoperiod, and subsequent recruitment is mainly influenced by factors not examined in this study such as predators, prey items, habitat availability, or post-settlement mortality. The broad range of physical environmental factors tolerated by Tasmanian blennies, and the suggested importance of biological factors, are discussed in relation to recruitment of estuarine rocky reef fish in general.

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I am not a native-English speaker, writing up of this thesis was the most difficult task. Although this thesis was corrected several times, its style is still not as good as if it was written by a native-English speaker. Consequently, I would like to thank the examiners who have definitely read my thesis with patience.

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CHAPTER 1

GENERAL INTRODUCTION

Understanding the processes affecting recruitment is a fundamental objective in fishery biology (Heath, 1992; Ré and Goncalves, 1993). The magnitude of annual recruitment to fisheries is often determined during the early life history stages, particularly during the larval and juvenile stages (Ré and Goncalves, 1993).

Recruitment in fisheries science is defined as the abundance of a year class at the age of entry to the fishery (Heath, 1992). Where the whole population is considered, including those individuals which are below harvest size, recruitment is considered to occur when larvae settle out of the plankton and have significant control over their distribution (Suthers pers. comm. cited by Sutton, 1991). It is well documented that recruitment of many of the world's fisheries are extremely variable (Cushing, 1974; Leiby, 1984) which has been attributed to many factors including variations in food abundance, predation, unfavourable advection, and climatic factors (Cushing, 1974; Iles and Sinclair, 1982). These factors may be divided into biological and physical factors and there is some debate over which has the greatest influence on variations in year class strength. The match/mismatch hypothesis (Cushing, 1975) and the member/vagrant hypothesis (Iles and Sinclair, 1982) focus the main arguments in support of biological and physical factors, respectively. The former suggests that larval survival is determined by the temporal overlap between larvae and the spring bloom in phytoplankton, while the latter proposes that unfavourable advection often ultimately determines recruitment.

In reality, both processes often probably work together. Biological and physical processes influencing recruitment are complex and interactions between factors tend to occur (Richards and Lindeman, 1987).

Biological factors

Hjort (1914), introduced the concept of a "critical period" which relates the strength of a year-class to the availability of planktonic food shortly after the larval yolk supply has been exhausted. This theory predicts that recruitment variability is linked to the interannual variation in the degree of

spatio-temporal overlap between the larvae and their food resources (Cushing, 1974, 1975; Lasker, 1981). The implication of this theory is that a lack of food, or a mismatch in larval fish and food organisms distribution, will be a principal regulator of year class strength (Hjort, 1914; Hunter, 1976; Lasker, 1987).

Several researchers have shown that the critical period for food supply and food availability is important in larval survival. Laboratory data suggests larval survival is dependent on food density (Theilacker and Dorsey, 1980; Tsai, 1991). Studies on larval survival in natural environments have also shown that timing and distribution of food supply is critical; Lasker and Smith (1977) and Scuda and Jerde (1977) showed that natural subsurface chlorophyll maximum layers may be important to the survival of larval anchovy (*Engraulis mordax*) and that these layers have relatively higher larval abundance. Distribution and richness of these layers will thus influence larval survival.

In the estuarine environment where productivity is high, starvation dependant larval mortality may not be as important as it is in the oceanic environment (Boesch and Turner, 1984). However, in temperate estuaries a peak in productivity occurs in spring and summer (Beckley, 1986; Jenkins, 1986; Miskiewicz, 1986; Roper, 1986; Gaughan et al., 1990) which is consistent with the spring/summer spawning/hatching of Tasmanian blennies (Cook, 1986; West, 1988). Larval abundance of many temperate species tends to overlap with zooplankton abundance which at its highest during the summer months (Grindley, 1981). This often results from timing of larval release. For example, Hart (1974) showed that first spawning of *Ammodytes marinus* (Raitt) is synchronized with the peak phytoplankton abundance. These observations appear to support the match-mismatch hypothesis where food availability is considered critical to larval survival.

In the concept of "critical periods", food availability is considered especially important at certain life stages - onset of feeding after yolk sack resorption is one such stage. In demersal fish, another critical period may exist when larvae settle from the plankton and assume a benthic lifestyle. If food availability does affect larval survival during this settlement period, then settlement should correlate with abundance of food. The production pulses hypothesis of Thresher et al. (1989) suggests that short-duration pulses of production translate into periods of high rates of larval survival and subsequent juvenile settlement. Thresher et al. (1989) investigated

the settlement of clinid *Heteroclinus* spp., a temperate marine rocky-reef fish, in the Derwent River Estuary in Tasmania and found pulses of settlement invariably preceded by brief, irregularly occurring peaks of phytoplankton production by 7-9 weeks. Their findings also support the match-mismatch hypothesis of Cushing (1975) and extend the idea of a 'critical period' of Hjort (1914, 1926) where larval survival is determined by the availability of food for first-feeding larvae.

Physical factors

The hydrographical and climatological factors that affect larval fish are density independent factors that can influence larval survival and hence subsequent recruitment (reviewed in Richards and Lindeman, 1987). The consensus view is that the most important climatic factor influencing the growth and survival of larvae is temperature (Leiby, 1984; Allen and Barker, 1990). Sudden changes in temperature can be detrimental - a discontinuity in surface water temperature appeared to cause the mass mortality of larval frigate mackerel in the Hawaiian Islands (Strasburg, 1959). Some authors report that larvae are more vulnerable to typical natural changes in temperature, especially low temperature, than they are to typical changes in salinity (Leiby, 1984; Merle, 1987 cited by Sutton, 1991).

In estuaries, the temporal and spatial pattern of temperature and salinity is known to be highly variable, generally more than in either freshwater or marine habitats (Stickney, 1959). This variability is induced by circulation patterns and seasonal changes in atmospheric conditions (Leggett, 1984). Consequently, a range of circulation and atmospheric factors may indirectly affect larval survival by altering temperature and salinity. These factors include wind strength, air temperature, rainfall, river discharge, current movements, and tides.

Hydrographic processes may also influence the distribution and recruitment of larvae in estuaries by affecting retention (Weinstein et al., 1980; Fortier and Leggett, 1982; Norcoss and Shaw, 1984). Hydrodynamic forces can aid transport of larvae into estuaries, but behavioural mechanisms are important in maintaining distribution. For example some larval fish appear to be able to control their horizontal distribution by vertical migration (Weinstein et al., 1980; Fortier and Leggett, 1982). Weinstein et al. (1980) suggested that larval fish might maintain position during ebb by "riding out" the current in the protection of boundary layers near the bottom and move upstream on the flood tide.

Iles and Sinclair (1982) suggested that larval recruitment is primarily governed by hydrographic processes and they termed this the member/vagrant or 'larval retention' hypothesis. This hypothesis conflicted with match/mismatch hypothesis of Cushing (1975). The larval retention hypothesis implies that stock structure, and perhaps abundance, is independent of reproduction, growth and other biological variables and determined by behavioural and environmental variables (Iles and Sinclair, 1982; Beyer, 1989). Primary behavioural aspects influencing larval survival are the selection of spawning grounds, and vertical movements by larvae to ensure retention.

Interannual differences in rates and direction of larval drift induced by changes in current direction and speed are known to have significant influences on larval survival, and ultimately on recruitment to adult stocks of marine fishes (Leggett, 1984). For example, Ekmann transport is known to directly influence the rates of larval drift of Atlantic menhaden (*Brevoortia tyrannus*) and Pacific hake (*Merluccius productus*) on the east and west coasts of North America, respectively. Year class strength in menhaden is positively correlated with the intensity of landward Ekmann transport during the period of larval drift, while year class strength in Pacific hake is negatively correlated with the intensity of offshore Ekmann transport (Nelson et al., 1979, Bailey, 1981). In years when transport rates are high, menhaden larvae are carried to their coastal nursery areas quickly and survival is enhanced (Nelson et al., 1979). This contrasts with Pacific hake, in which, when transport rates are high, larvae are more rapidly advected offshore and away from the most productive nursery areas, thereby reducing survival (Bailey, 1981). The delivery of larvae of oceanic species to inshore nursery areas may also be influenced by hydrographic events. A number of studies of fishes and invertebrates in temperate environments have related strong settlement events to oceanographic conditions favourable for the movement of nektonic larvae to juvenile habitats (e.g. Cowen, 1985; Ferell et al., 1991).

The moon's influence is most marked in the sea mainly because of its effect upon the tides and consequently the majority of examples of rhythms with lunar or tidal periods are found in marine animals (Gibson, 1978). Lunar cycle and tidal phase therefore appear to be important in determining recruitment patterns (e.g. McFarland et al., 1985; Thorrold, et al., 1994a). Lunar phase appears to act both on spawning behaviour and subsequent timing of larval release (e.g. Johannes, 1978; Thresher, 1984)

and also on larval behaviour (Allen, 1972). Allen (1972) suggested that moon light may enhance off-reef movements of photopositive hatchlings by attracting them toward the water's surface. The photopositive behaviour of the hatchlings may be another adaptation that promotes dispersal from the nest site (Doherty, 1983). Larval behaviour and subsequent recruitment may be affected by lunar cycles as diel or vertical migration patterns (Kavaliers, 1982) and settlement patterns can be influenced (Shenker et al., 1993; Thorrold et al., 1994a).

Age and Growth by Otolith Analyses

Age in fish can be determined by the examination of growth zones or checks which appear on the hard parts such as vertebrae, spines, opercula, scales, skull bones, and supra occipital crests and otoliths (De Bont, 1966). Scales are often used but this technique is obviously of no value for scaleless fish such as the Tasmanian blennies. Qasim (1957) successfully used otoliths in ageing *Blennius pholis* and this technique was later used by Cook (1986) to determine the age and growth of Tasmanian blennies.

The otoliths of fish are analogous to the otoconia of other vertebrates but are relatively larger and have complex morphologies which are species specific (Lowenstein, 1971; Popper and Coombs, 1980). Three pairs of otoliths occur in teleosts and they each differ in location, function, size, shape, and ultrastructure. These three pairs of otoliths are termed the lapilli, sagittae, and asterisci (Secor et al., 1991). The microstructural units of otoliths used in aging fish larvae are layers of calcium carbonate crystals which are deposited periodically on an organic matrix. The layers of crystal deposition are termed incremental zones and breaks in crystal formation are called discontinuous zones (Campana and Neilson, 1985). Two consecutive zones together form each otolith increment, or ring, visible under transmitted light as adjacent bands of light (incremental) and dark (discontinuous) material. The discovery by Pannella (1971) of daily increments within the otolith's microstructure provided the ability to collect information about age estimates of fish, thus allowing the estimation of population growth curves from length-at-age data. Campana and Neilson (1985) and Jones (1986) reviewed numerous applications of information derived from otolith microstructure among which are : (1) age determinations; (2) daily growth rate estimations; (3) mortality; (4) migratory and environmental history; (5) competition; (6) abundance; (7) condition and (8) taxonomy.

The quantification of some of these life history parameters is essential for the evaluation of the causes underlying recruitment variability, especially as described by Hjort's (1914) critical period concept. Otolith analysis can provide additional information to size at age. Changes in increment morphology often occur at times of ecological and physiological transitions in development such as metamorphosis, and may provide information on processes such as settlement and recruitment (Brothers and McFarland, 1981; Victor, 1982, 1983, 1986).

The back-calculation method of determining settlement and recruitment has several attributes (Doherty, 1991). First, over short periods, it may resolve the temporal pattern of recruitment even better than most visual surveys for a lower investment of valuable field time. Secondly, it can be used to resolve settlement in species with cryptic juveniles that cannot be counted reliably. Thirdly, and most importantly, major variations in settlement intensity can still be detected in samples collected several months after the event.

Study species

The Tasmanian blennies *Parablennius tasmanianus tasmanianus* (Richardson, 1849) are fish which have three different stages in their life history. Member of family Blenniidae are cryptobenthic inhabitants of rocky coastlines and are widely found in temperate and warm marine coastal habitats. Tasmanian blennies are good subjects for field studies as they are demersal and territorial, generally staying in a relatively small area where can be observed over time (Cook, 1986). They are common fish and are easy to observe in the tide pools and shallow coastal habitats around Tasmania. They are also the only Tasmanian representative of the Family Blenniidae (Last et al., 1983) so it is relatively simple to distinguish their larvae from those of other fish in plankton samples.

Despite their advantages as subjects for scientific research, they have rarely been studied in the southern hemisphere. Only a few scientific studies on reproductive biology focused on Tasmanian blennies (Cook, 1986; West, 1988; Mills, 1994). Other researchers have used Tasmanian blennies as bioassay animals for laboratory based toxicology studies and as an environmental indicator species (Deavin, 1993). Little is known of the ecology or population dynamics of Tasmanian blennies. The objective of this study was to determine the major factors influencing the hatching, larval abundance, and settlement of Tasmanian blennies.

To assess the importance of food supply, the effect of pulses in phytoplankton production (chlorophyll-a) was monitored in relation to the hatching, larval abundance, and settlement of Tasmanian blennies. The relationship between the abundance of larvae and the number of newly settled blennies was also determined in attempt to understand critical periods for survival. The effect of physical factors on hatching, larval abundance, and settlement was also assessed, including lunar cycles, tide, wind, rainfall, river discharge, water temperature and salinity. Variability in growth rates of marine fish larvae can cause important fluctuations in recruitment levels (Houde, 1987; 1989). Therefore, growth rates from length-at-age data of blenny larvae were also compared between years and sampling sites.

CHAPTER 2

GENERAL MATERIALS AND METHODS

2.1 THE STUDY SPECIES

The Tasmanian blenny *Parablennius tasmanianus tasmanianus* (Richardson, 1849) is the only Tasmanian representative of the Family Blenniidae, a group of fishes that is widely found in temperate and warm marine coastal habitats (Fig. 2.1 and Fig. 2.2). It is a member of the tribe Blenniini, of which there are 15 genera and 70 species (Bath, 1977). *P. t. tasmanianus* is found around the coastline of Tasmania, and along the south-east mainland Australia, from Jervis Bay (New South Wales) in the north, to Point James (South Australia) in the west.

The Tasmanian blenny is a cryptobenthic inhabitant of rocky coastlines, and is commonly found just below the low tidemark and in adjacent tide pools. It is omnivorous, grazing on a range of benthic plants and animals, especially red algae and colonial hydroids, and also eats a variety of crustaceans, molluscs and polychaetes. This species is generally diurnal but also has a crepuscular component in its feeding habit (Cook, 1986).

Although it is quite widespread and common around the coastlines of south-eastern Australia, the Tasmanian blenny has been the subject of only a few scientific studies. Brief comments on its taxonomy and habits appeared in Edgar et al. (1982), Last et al. (1983), and Hutchins and Swainston (1986), while some details on its home ranging behaviour was given by Evans (1982). Cook (1986) and West (1988) describe the species reproduction. They reported that the Tasmanian blenny spawns frequently over a spring/summer breeding season that can last up to four months. Females can produce 25,000-30,000 eggs annually although when food is scarce they have smaller batches and spawn less often over a shorter period. Cook (1986) reported that both egg size and fecundity were affected by food availability. Blennies produce demersal eggs, which are tended by the male. Cook (1986), West (1988) and Mills (1994) report that both incubation period and larval size at hatching correlate negatively with water temperature during incubation. The incubation time of blenny eggs was 22 days at 17°C and larval size at hatching was 4.3 mm TL

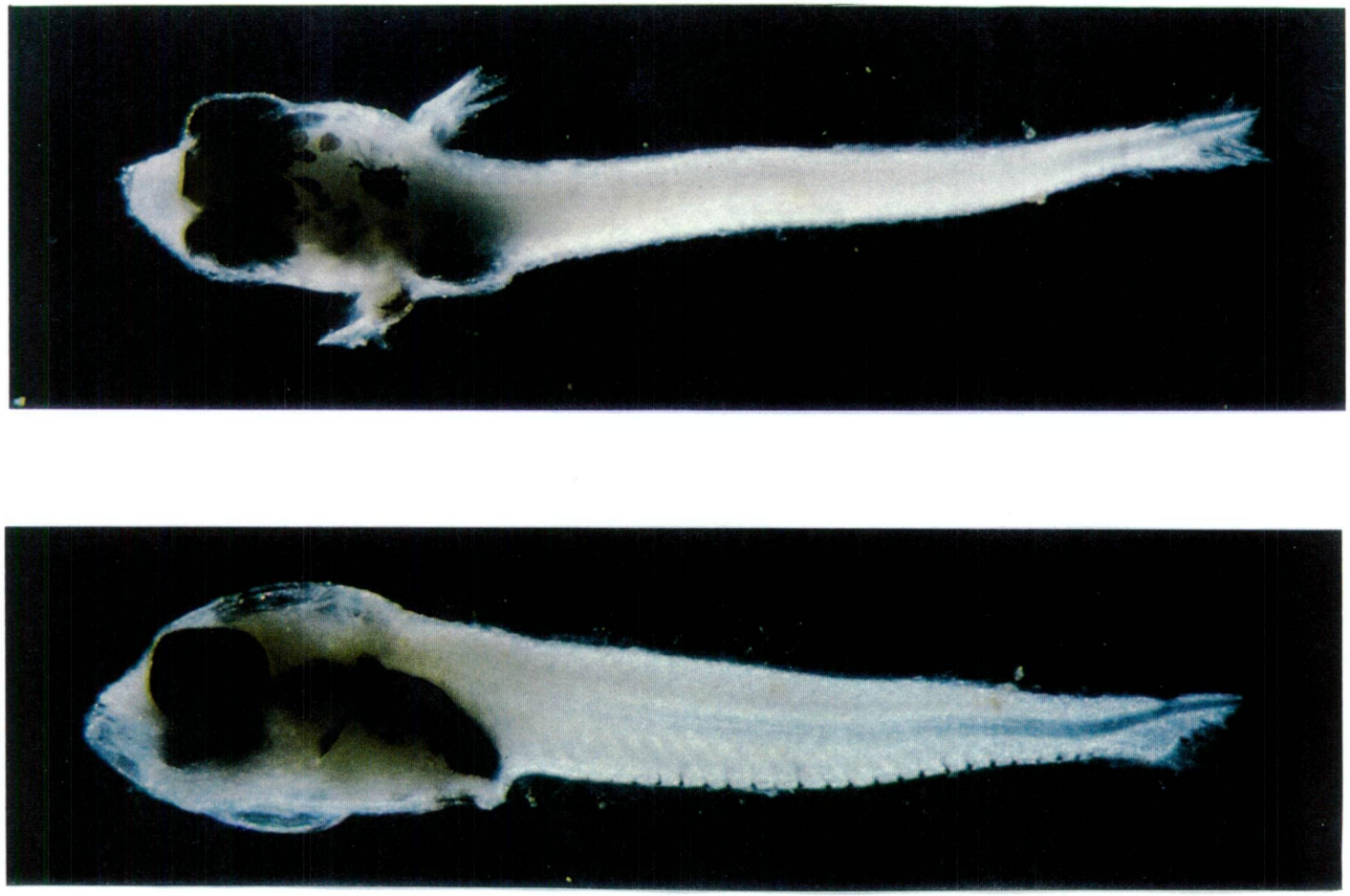

Figure 2.1 The Tasmanian blenny larva
Parablennius tasmanianus tasmanianus 5.8 mm standard length (Richardson, 1896).

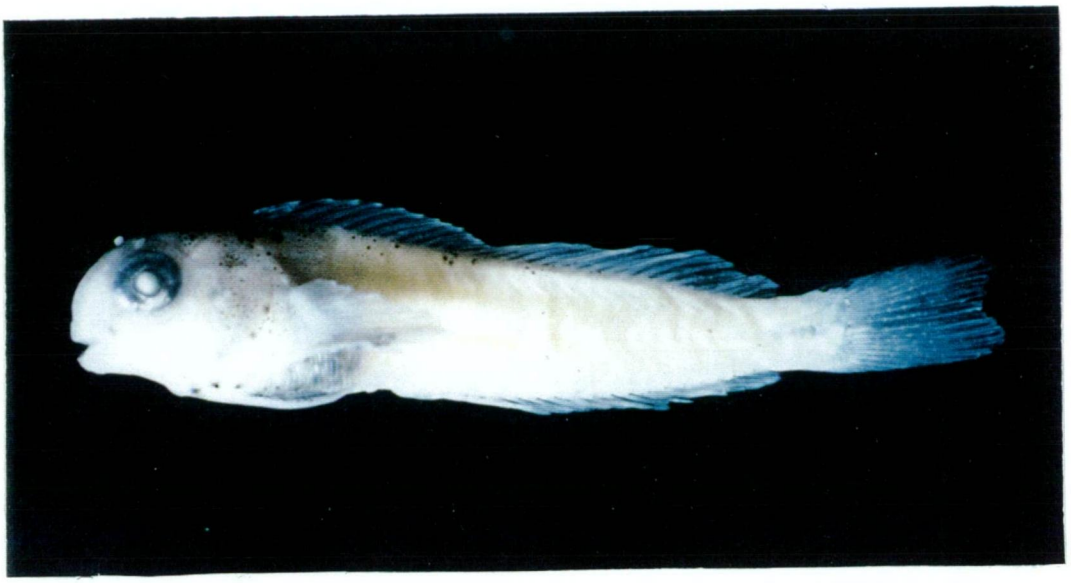

Figure 2.2 The Tasmanian blenny.
Parablennius tasmanianus tasmanianus (Richardson, 1896).
17.5 mm standard length newly settled juvenile.

(Cook, 1986), while water temperature of 20°C the incubation period was 12 days and larval size was 3.6 mm TL (West, 1988). Mills (1994) incubated eggs at water temperature of 15°C, 18°C, 21°C, and 24°C. He found that the incubation periods were 27 days, 18 days, 12 days, and 11 days; respectively and sizes at hatching were 4.7 mm, 4.5 mm, 4.2 mm, and 3.9 mm; respectively. Laboratory temperatures were higher than typical in the field, implying that both the incubation time and the length of newly hatched larvae are greater than the 17 ± 6.5 days, and 4.2 ± 0.4 mm SL found in the laboratory.

The larvae are similar to the larvae of other blenniids. Observations in the laboratory indicated that a small yolk sac was present at hatching but resorption was completed within 2 to 3 days (Cook, 1986; West, 1988). Larvae hatching at higher temperatures possessed relatively larger yolk sacs than those incubated at lower temperatures (Mills, 1994), although this observation was not quantified. In some other blennioid fish, yolk-sac absorption occurs mainly within the egg (Leis and Rennis, 1983; Gunn and Thresher, 1991).

Duration of the planktonic stage of larvae reared in the laboratory ranges from four to six weeks, averaging 36 days (J. Deavin and D. Mills, personal communication). Newly hatched larvae are positively phototactic and in their natural environment probably become planktonic at this stage. As in other littoral fish, hatching takes place primarily at night. In their natural environment this would allow the larvae to become planktonic, move into the surface currents and disperse into deeper water under the cover of darkness. Larvae feed on zooplankton and marine algae after remaining in the plankton for a couple of months, though there are few details available regarding larval ecology. The mechanism by which late-stage larvae are transported inshore and back into the littoral zone is unclear.

The Tasmanian blenny matures in its first year and may survive more than six years, reaching a length of 130 mm. Its pattern of growth is typical of most other cryptobenthic fish and is most rapid during the first two years of life (Cook, 1986).

2.2 STUDY SITE

The main study area was a large embayment in southeast Tasmania, (approximately at latitude 42° 57'S and longitude 147° 20'E, Fig. 2.3) known as Storm Bay. Storm Bay is a large and relatively deep estuary that

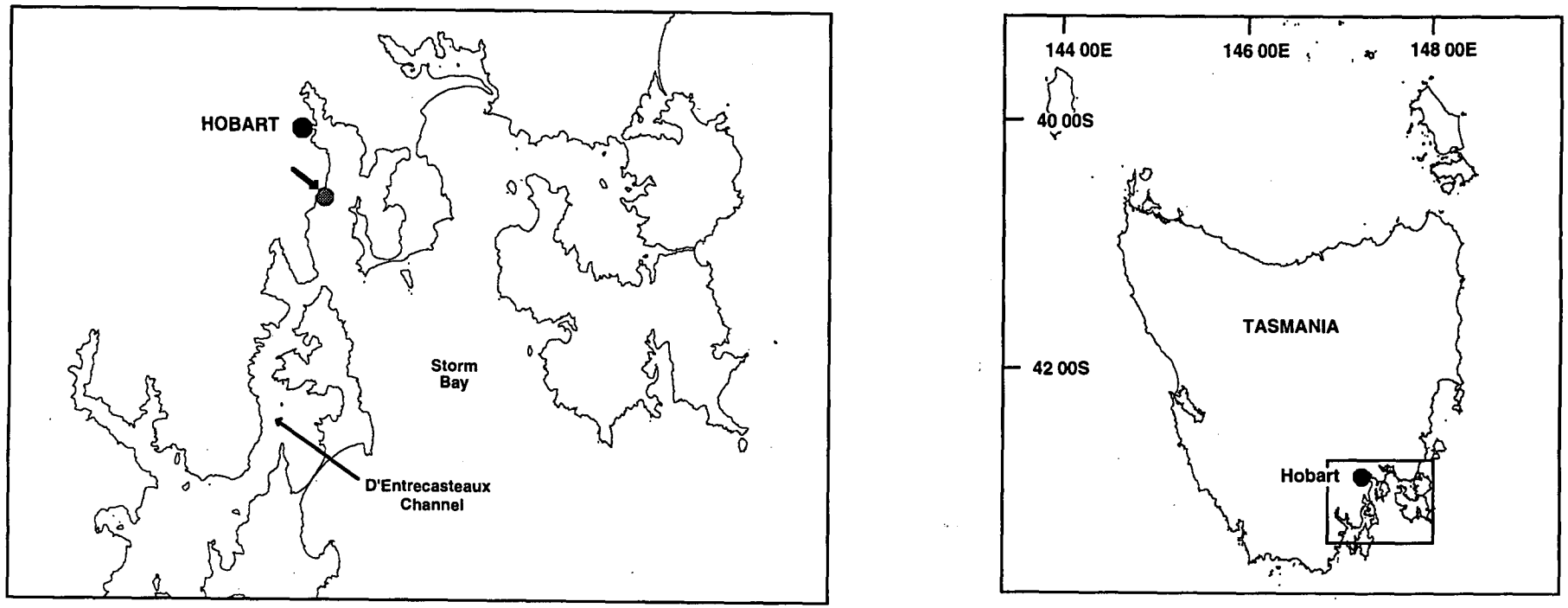

Figure 2.3. Sampling station in Derwent River Estuary in Storm Bay; inset shows position of Storm Bay relative to east and west coast of Tasmania (thick and short arrow indicates a station)

covers an area of approximately 500 km^2. Most of the bay (approximately 95%) is between 30 and 85 m deep. There are few houses close to the bay's shoreline which is mostly bounded by natural bush or cleared farmland. Both the Derwent and Huon rivers flow into Storm Bay and at times it receives intrusions of subtropical and subantarctic water (Nyan Taw and Ritz, 1979).

South-eastern Tasmanian coastal waters are a complex mixture of subantarctic and subtropical water masses (Harris et al., 1987) with the subtropical convergence being the boundary between these water masses (Deacon, 1945; 1982). The convergence, as measured in the surface currents, runs east from the east coast of Tasmania towards New Zealand (Wyrtki, 1960).

Cooper et al. (1982) and Clementson et al. (1989) reported on the physical and biological oceanography of the bay. In brief, the bay has a relatively small freshwater input, so salinity over most of the bay and at depths greater than a few centimetres are close to that of normal sea water. Tides and winds predominantly affect the currents which tend towards a clock-wise rotation.

Seasonal cycles of production in the water-column are typical of inshore temperate areas, with the abundance of phytoplankton and zooplankton peaking in spring and autumn. The time and pattern of production differs from year to year due, in part, to variations in the position of the main coastal currents (Newell, 1961; Harris et al., 1987) and irregularities in the timing of strong wind events that cause mixing of the water column in Storm Bay and local enrichment of the photic zone (Clementson et al., 1989; G. Harris et al. in preparation).

Larval fish sampling, water sampling and recruitment monitoring were done at points all around Storm Bay, but concentrated mainly in an area on the south shore of the bay, near the suburb of Taroona. This is a long, rocky shoreline, near the Tasmanian Department of Sea Fisheries main laboratory. *P. t. tasmanianus* is extremely common in this area, which appeared to be typical of the habitat it occupies.

2.3 FIELD SAMPLING

2.3.1 Larval Fish Sampling

Sampling of larval fishes was done using a 5 m launch (FRV Ophelia). Sampling were taken approximately weekly intervals during spring and summer from 12th October 1992 to 3rd February 1993 (16 samples) and 5th November 1993 to 18th February 1994 (15 samples).

In 1992-93, samples were collected with a 1 m diameter ring net, 4.0 m long and with 500 μm mesh. Samples were taken at a single station, and consisted of three replicate surface tows perpendicular to the shoreline and spaced at 0.35 nautical mile intervals (Fig. 2.4a). For each sample, the net was towed behind the boat just below the surface in a straight line on a 20 m long rope, starting approximately 30 metres from the shoreline. Total duration of the tow was ten minutes, at a speed of 2 to 3 knots. As the first four weeks of sampling resulted in the capture of only a few blenny larvae, an additional deeper tow was added to the sampling program from 24th November 1992 onwards, with the net being towed at a depth between 5 and 13 metres. This supplemental tow was made after the surface tows, and was done parallel to the shoreline and approximately 200 metres out from the shore. This strategy was based on preliminary data by Thresher and Mills (1990, unpublished report) that found a concentration of blenny larvae in that areas. The samples were preserved in 95% ethanol.

In 1993-94, ichthyoplankton samples were collected by a pair of 50 cm diameter bongo nets with 333 μm mesh. The bongo nets were used so that two separate but approximately equivalent samples could be collected. One of the resultant samples was fixed in 5% formalin buffered with borax which maintained larvae in optimal condition for a gut content study, and the other in 95% ethanol to maintain otoliths for aging and assessment of growth rates. Sampling comprised four replicate surface tows and one subsurface tow, except on 18th February 1994, when the subsurface tow sample was abandoned due to a large amount of jelly fish in the net. In each sample, the bongo nets were towed below the surface in a spiralling pattern away from the shore in order to avoid the problem of patchy larval distribution and the turbulence created by the boat's wake. The track of towing was still approximately perpendicular to the shoreline (Fig. 2.4b). A deeper tow was made parallel to the shore and approximately 200 m out from the shore after the other tows were completed. A depth gauge was attached to the net to record the depth to

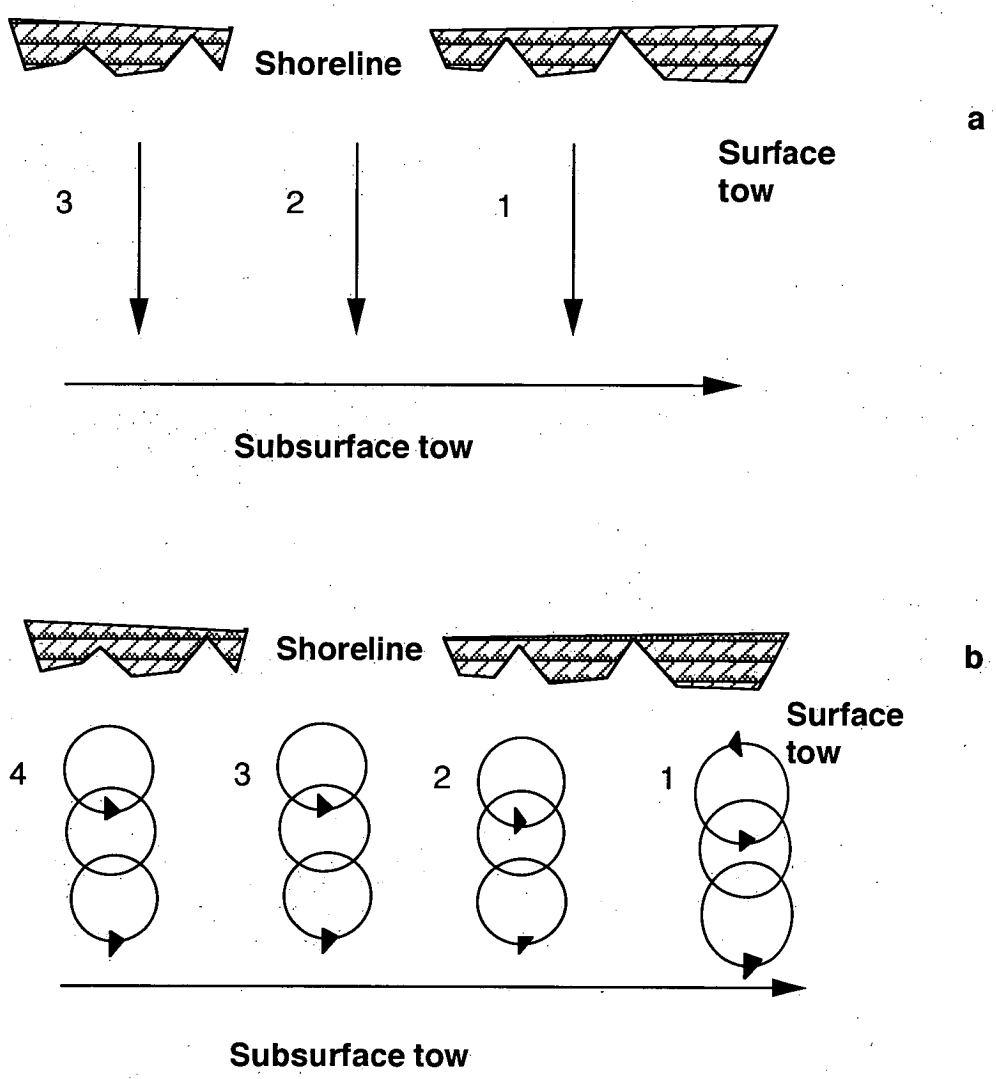

Figure 2.4. Diagram of towing net
a. towing in 1992-93
b. towing in 1993-94

which it was lowered. This showed that the net was towed at a depth between 5 and 13 metres.

Preservation in 95% ethanol prevents dissolution of the otoliths and causes little shrinkage of fish (Methot and Kramer, 1979; Theilacker, 1980). Consequently, in the absence of hand data on shrinkage of preserved larval *P. t. tasmanianus*, larval sizes and growth rates are not adjusted for shrinkage.

Sampling was done from late morning to mid-day, in order to maximize the likelihood that the larvae had food in their digestive tract (Blaxter, 1965; Kjelson et al., 1975; Last, 1980; Young and Davis, 1990, 1992).

2.3.2 Comparison of Larval Sampling Techniques

Because different techniques were used to collect ichthyoplankton in 1992-93 and 1993-94, the efficiency of these different sampling strategies was compared.

The comparison was based on six sampling strategies: straight surface tows using a ring net and a pair of bongo nets, circular surface tows using a ring net and a pair of bongo nets and straight subsurface tows using a ring net and a pair of bongo nets. Three trials were carried out for each method on 2nd November 1994, 19th December 1994, and 2nd February 1995. These dates were chosen to provide a range of larvae abundance, based on results from 1992-93 and 1993-94. Each trial consisted of three replicates of each method of sampling (Table 2.1).

Table 2.1. Different sampling strategies trial was carried out. SST=straight surface tow, CST = circular surface tow, SSF = subsurface tow, √ = sampling, x = no sampling.

SAMPLING	1 m ring net			a pair of 50 cm bongo net		
DATE	SST	CST	SSF	SST	CST	SSF
2 NOV 94	√	√	√	√	√	√
19 DEC 94	√	√	x	√	√	x
2 FEB 95	√	√	√	√	√	√

A calibrated flowmeter (General Oceanic Standard mechanical flowmeter Model 2030R) was fixed at the centre of the mouth of each net to measure the volume of water filtered by each net during each tow. Flow meters were calibrated before and after sampling. Towing duration for each method was 10 minutes and towing speed was 2 to 3 knots. All samples were fixed in 5% formalin buffered with borax and then taken to the laboratory for analysing. Comparison was based on calculating the number of larvae per 250 m^3 sea water volume for each sample.

The volume of water filtered by the 1 m ring net during the three types of tow; straight surface, spiralling surface and subsurface did not differ significantly ($P > 0.05$, F-test, ANOVA). The volume of water ranged from 136.9 to 599.5 m^3, mean = 362.95, S.D. = 103.72, n = 23. Likewise, there was no significant difference between the water volume filtered by a pair of 50 cm bongo nets for the three types of tow ($P > 0.05$, F-test, ANOVA, range from 60.48 to 165.99 m^3, mean = 103.09, S.D. = 25.45, n = 24). Not unexpectedly, the volume of water filtered by the tow net types differed substantially ($P < 0.001$), due to the larger mouth opening of the 1 m ring net.

The subsurface tow was not done during the second sampling trip because of rough sea conditions. Consequently, data for subsurface tows were not analysed because the sample size was too small. Prior to analysis, larval number was log transformed to reduce heteroscedasticity. Analysis was based on three factors ANOVA (dates vs net type vs tow type). When adjusted for volume of water filtered, there were no differences in the abundance of larvae collected by a 1 m ring net and a pair of 50 cm bongo nets ($P > 0.05$), nor any difference between the two types of tow ($P > 0.05$). There was, however, a significant difference in the numbers of larvae caught on different sampling times ($P < 0.01$). None of the interaction terms were significant.

I, therefore concluded the estimates of larval abundance made using the two sampling techniques were directly comparable, once they were adjusted for volume of water filtered.

2.3.3 Sampling Newly Settled Juveniles

The settlement of blennies was investigated by sampling newly settled juveniles in three tide pools in the rock reef platform. Sampling was done at fortnightly intervals during spring and summer (between November and

March) from November 1992 to March 1995. Newly settled juveniles were caught during low tide. A 3:1 mixture of the ichthyocide "Rotenone" and 95% ethanol were used to poison the tide pool so that fish could be collected. The amount used varied from about 0.25 to 1 L depending on the size of the pool. Rotenone causes the blennies to swim up to the surface of the water where they remain for some time and can easily be captured using a hand net. Each pool was carefully searched for fish after the rotenone solution was applied. The search was continued for at least 5 minutes after catching the last blenny to reduce the chance of any being overlooked. Captured fish were preserved in 95% ethanol and then taken to the laboratory. Newly settled *P. t. tasmanianus* are transparent other than several conspicuous pigment spots. Older juveniles develop pigmentation rapidly.

2.4 LABORATORY ANALYSIS

2.4.1 Identification and Length Measurement

All larvae were sorted from the plankton samples in a rotatable sorting ring under a dissecting microscope. Species other than the blennies were identified to only family level and counted (Appendix 1). Blenny larvae were identified on the basis of morphology and pigmentation as described by Cook (1986) and West (1987). Standard length (SL: tip of the snout to tip of the notochord, or the hypural crease in post-flexion larvae) was measured to the nearest 0.1 mm under a dissecting microscope with an ocular micrometer.

Standard length (SL: tip of snout to tip of the hypural crease) of juveniles was measured to the nearest 0.1 mm with a vernier calliper.

2.4.2 Otolith Analysis

2.4.2.1 Preparation

Specimens for otolith analysis were randomly selected from each ethanol-preserved sample, up to a maximum of 20 larvae per sample. For samples with more than 20 larvae, sub-samples were taken in proportion to the number of individuals in each developmental stage to ensure an unbiased estimate of the age distribution of larvae.

The otolith microstructure of all blenny larvae obtained in 1992-93 was examined, whereas only larvae which were preserved in alcohol from 1993-94 had their otolith microstructure examined. Larva was placed in a drop of water on a microscope slide and otoliths were teased out under cross polarized light with electrolytically-sharpened tungsten needles. Otoliths were cleaned and were air-dried before being placed with their flat sides against the microscope slide in immersion oil for microscopic examination.

Some otoliths from juveniles were larger and thicker than those of larvae. These required further preparation so that a thin section could be obtained and increments could be viewed satisfactorily under a light microscope. Otoliths removed from juveniles were cleaned in distilled water and then air-dried. Each otolith was embedded in a mixture of Araldite epoxy resin and Araldite hardener (10:1 by volume). They were left overnight in an oven set between 50°C and 60°C. The lateral surface of each otolith was then gently ground to the primordium on one side, first by hand using 1200 grade of wet carborundum paper and then by grinding machine with 6 and 3 μm diamond paste and gently polished with 0.1 mm aluminium oxide, Al_2O_3 (Linde B) on polishing tray by hand.

2.4.2.2 Examination and Aging

Otoliths were viewed under transmitted light, using a video system fitted to a compound microscope. Otolith increments, each consisting of a light and a dark zone when viewed with transmitted light, were counted from images on a video monitor at microscope magnifications of 400x or 1000x. No difference between number of increments of sagittae and lapilli were found ($t = .119$, $n = 40$, $P > 0.05$, two tailed t-test).

Counts were usually made on the lapilli but were made on sagittae if these were unreadable. Counts were made along the posterior radius which was consistently the best line for increment counting. They were made between the first dense and well defined increment, the hatching-mark (Age 0) (mean radius ± S.D., 17.9 ± 0.84), and the otolith periphery. Otolithic age for the larvae examined was defined as the number of increments external to this hatching mark. Specimens were examined double blind by the same reader and the mean was used. Only specimens for which increment counts were identical for both left and right otoliths, and for successive readings, were accepted.

The age at the end of the larval period (i.e., the duration of the larval stage) was assessed from a well-defined settlement mark in the otolith (Fig. 2.5), the utility of which was verified by examining otoliths of still transparent, newly settled early juveniles in the field. A settlement mark appeared to be present on the otoliths of newly settled recruits and absent on the otoliths of planktonic larvae. All Tasmanian blennies captured in tide pools, including large adults, had a conspicuous transition in the character of the increments. Juveniles settled on their first day into tide pools had this transition on the edge of their otoliths. At this transition, the previously prominent dark lines which delineated each increment abruptly disappeared. Regular increments only reappear after a band without discrete increments is formed. The otoliths of some juveniles which had settled in tide pools displayed some exceptionally discrete increments with a much narrower width outside the settlement mark.

2.4.2.3 Back-Calculation of Hatching-date and Settlement-date

Back-calculated hatching dates of *P. t. tasmanianus* that survived until the time of sampling were obtained by subtraction counts of growth increments from the calendar date of capture. Settlement date was estimated by counting the number of increments after the settlement mark to the edge of the otolith, and back-dating from the date of capture.

2.4.3 Validation of Aging Procedures for Tasmanian Blenny Otoliths

Both the precision and accuracy of otolith analysis used for the estimation of larval age and growth should be validated (Geffen, 1995).

The time of formation of the first increment was determined by examining specimens born in captivity. Fertilised eggs were incubated, hatched and reared at National Key Center, Department of Aquaculture, University of Tasmania at Launceston (supplied by D.G. Mills). Incubation temperature was 17°C and the light cycle followed the natural photoperiod. Six newly hatched larvae which had already absorbed their yolk-sacs were examined. At hatching, the sagittae and lapilli were developed and conspicuous indicating otoliths formed during embryonic development. Otoliths of Age 0 (i.e., the first day of life) display a spherical primordium surrounded by two conspicuous dark broad bands close to otolith center.

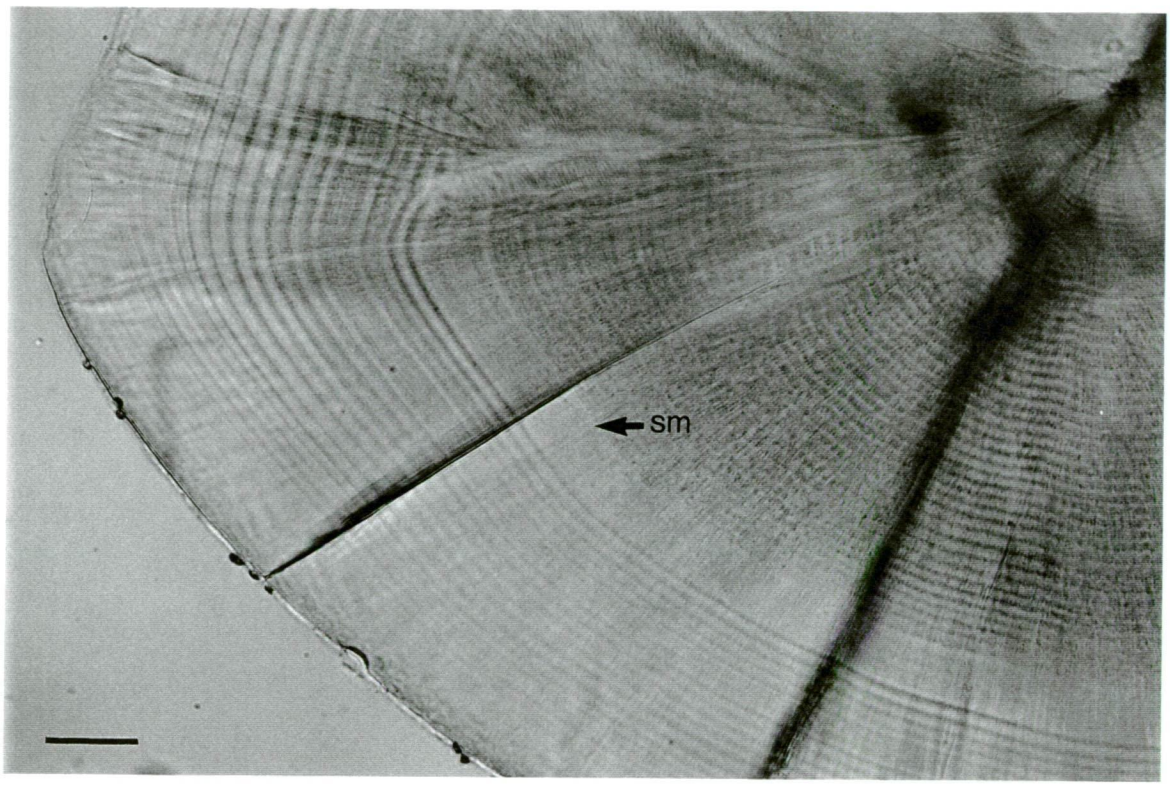

Figure 2.5. *Parablennius tasmanianus tasmanianus*. Lapillus from 28.5 mm (SL) juvenile caught from Taroona tide pools. Settlement mark is shown in the otolith (Arrow sm); Scale bar = 20 μm.

They were apparently laid down before hatching. Between the primordium and the second broad band, the structure of the otolith was variable. A hatching mark, which is apparently laid down at hatching, was not readily discernible but may have formed close to the edge of the otolith. The hatching mark was clearly seen in the otoliths of 0 d-old and 3 d old larvae (Fig. 2.6a and 2.6b). The radius of the hatching mark of reared larvae varied slightly between specimens (x =17.9 μm, range = 16.8 - 19.5 μm, n = 22).

In the otoliths of wild larvae, a strongly delineated increment was evident in most specimens, that was located approximately the position as the hatching mark in reared larvae (x = 17.6 μm, range = 15.4 - 19.8 μm, n = 22). The radius of the hatching mark of reared larvae did not differ significantly from its apparent equivalent in wild-caught larvae ($P > 0.05$, two tailed t-test). The microstructure of the otolith differed markedly on either side of this hatching mark. Inside, there was little evidence of consistent structure (other than two conspicuous bands close to the center); beyond the hatching mark, increments were unambiguous, increasing in width exponentially (Fig. 2.7). Otolithic age for the larvae was defined as the number of increments external to this hatching mark. This age was used in analysis of growth, hatching date and settlement date back-calculation.

The hypothesis that increments in the otolith are formed daily was tested by examining the otoliths of reared larvae. Otoliths of 3 d-old larvae exhibited the hatching mark succeeded by three increments (Fig. 2.6b).

2.5 STATISTICAL ANALYSIS

The results were analysed using analysis of variance (ANOVA). The relationships between some variables were tested using linear regression and correlation coefficient. Homogeneity of variance was tested using Bartlett's Test. Data distribution was tested for normality using Shapiro-Wilk W Tests. The results were considered to be statistically significant if $P < 0.05$. Statistical packages of JMP 3.1 and Statview 4.02 were used for analysing.

Some of the environmental variables may have had an effect on reproductive processes (like ovulation or spawning) and as a consequence affect reproductive output (for example, abundance of larvae or newly settled juveniles). Thus there may be a time lag between the

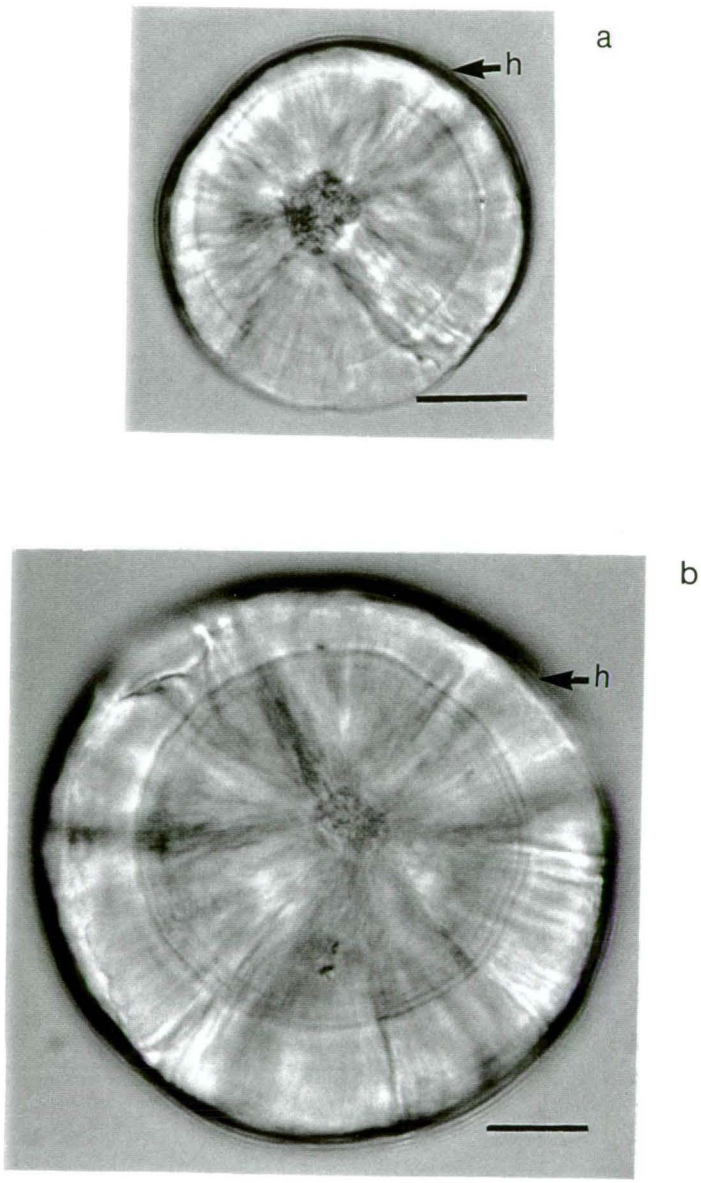

Figure 2.6a. *Parablennius tasmanianus tasmanianus*. Lapillus (a) and sagitta (b) from newly hatched larva (0 d posthatch) 4.2 mm (SL) larva that had been reared in an aquarium. Hatching mark (radius = 19.54 μm for lapillus and 32.11 μm for sagitta) is shown at the peripheral of the otolith (Arrow h); Scale bar = 10 μm.

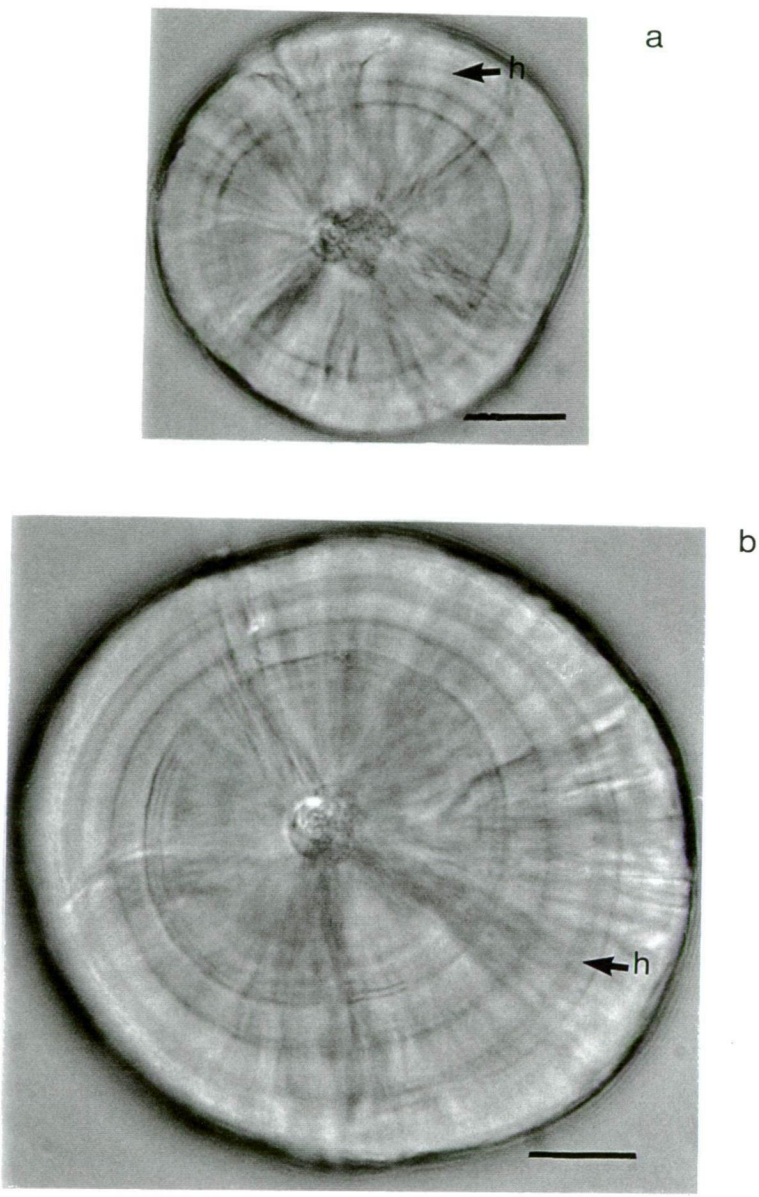

Figure 2.6b *Parablennius tasmanianus tasmanianus.* Lapillus (a) and sagitta (b) from 3 d old 5.1 mm (SL) larva that had been reared in an aquarium. Three narrow daily rings are shown after hatching mark (radius of hatching mark = 16.83 μm for lapillus and 28.71 μm for sagitta) of the otolith (Arrow h); Scale bar = 10 μm.

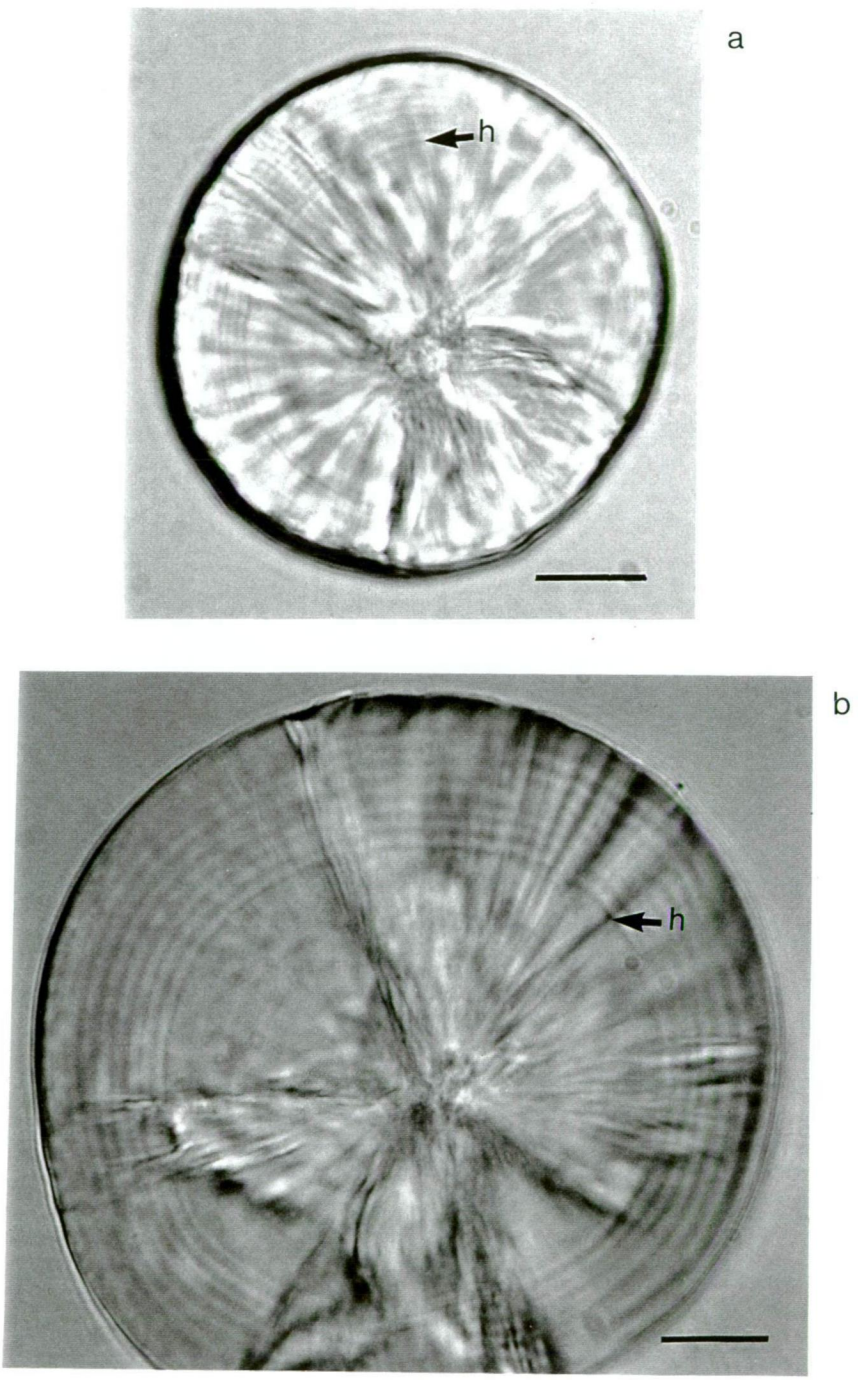

Figure 2.7. *Parablennius tasmanianus tasmanianus*. Lapillus (a) and sagitta (b) from 9 d old 5.1 mm (SL) larva caught from Taroona sampling site (Arrow h); Scale bar = 10 μm.

peak in environmental variable and resulting peaks in larval or juvenile abundance. Reasonable lag times were determined on the basis of blenny biology and a range of lags were used for statistical analysis.

The lags time used for analysing the possible effect of some environmental variables on the abundance of larvae were 5 d lag because age of larvae collected during sampling period was from 0 to 5 d. For lag of weeks was from lag of 0 to 3 w because incubation period of blennies were 3 w (21 days in average, Cook, 1986; West, 1988; Mills, 1994).

The reasonable lag times for analysing the possible effect of some environmental variables on the number of back-calculated newly hatched blennies were 4 w because the incubation period of blenny was 3 w approximately and plus 1 w before laying eggs of blennies (adult biology of blennies).

The reasonable lag times for back-calculated newly settled blennies were 13 w lag because plankton larval duration of blennies were 9 w at the longest (36 - 69 days, see chapter 3) and incubation period was 3 w plus 1 w for adult biology before laying eggs.

The reasonable lag of days for analysing the relationships between some environmental variables and number of back-calculated newly settled blennies was also determined if the variables showed high values one week before settlement.

2.6 DATA PRESENTATION

Pattern of distribution of any biological factors, physical factors, larval abundance, number of newly hatched blennies and number of newly settled blennies were shown by calendar week (Table 2.2).

Table 2.2 Calendar week during sampling period from 1992 to 1996

Year 1992-93		Year 1993-94		Year 1994-95		Year 1995-96	
Date	Calendar week	Date	Calendar week	Date	Calendar week	Date	Calendar week
12-18.10.92	42	3-9.10.93	41	9-15.10.94	42	15-21.10.95	42
19-25.10.92	43	10-16.10.93	42	16-22.10.94	43	22-28.10.95	43
26.10.92-1.11.92	44	17-23.10.93	43	23-29.10.94	44	29.10.95-4.11.95	44
2-8.11.92	45	24-30.10.93	44	30.10.94-5.11.94	45	5-11.11.95	45
16-22.11.92	47	31.10.93-6.11.93	45	6-12.11.94	46	12-18.11.95	46
23-29.11.92	48	7-13.11.93	46	13-19.11.94	47	19-25.11.95	47
30.11.92-6.12.92	49	14-20.11.93	47	20-26.11.94	48	26.11.95-2.12.95	48
7-13.12.92	50	21-27.11.93	48	27.11.94-3.12.94	49	3-9.12.95	49
14-20.12.92	51	28.11.93-4.12.93	49	4-10.12.94	50	10-16.12.95	50
21-27.12.92	52	5-11.12.93	50	11-17.12.94	51	17-23.12.95	51
28.12.92-3.1.93	53	12-18.12.93	51	18-24.12.94	52	24-30.12.95	52
4-10.1.93	54	19-25.12.93	52	25-31.12.94	53	31.12.95-6.1.96	53
11-17.1.93	55	2-8.1.94	54	1-7.1.95	54	7-13.1.96	54
18-24.1.93	56	9-15.1.94	55	8-14.1.95	55	14-20.1.96	55
25-31.1.93	57	16-22.1.94	56	15-21.1.95	56	21-27.1.96	56
1-7.2.93	58	23-29.1.94	57	22-28.1.95	57	28.1.96-3.2.96	57
8-14.2.93	59	30.1.94-5.2.94	58	29.1.95-4.2.95	58	4-10.2.96	58
15-21.2.93	60	6-12.2.94	59	5-11.2.95	59	11-17.2.96	59
22-28.2.93	61	13-19.2.94	60	12-18.2.95	60	18-24.2.96	60
1-7.3.93	62	20-26.2.94	61	19-25.2.95	61	25.2.96-2.3.96	61
8-14.3.93	63	27.2.94-5.3.94	62	26.2.95-4.3.95	62	3-9.3.96	62
15-21.3.93	64	6-12.3.94	63	5-11.3.95	63	10-16.3.96	63
22-28.3.93	65	13-19.3.94	64	12-18.3.95	64		
29.3.93-4.4.93	66	20-26.3.94	65	19-25.3.95	65		
5-11.4.93	67	27.3.94-2.4.94	66	26-31.3.95	66		
12-18.4.93	68	3-9.4.94	67	1-7.4.95			
19-25.4.93	69						
26.4.93-2.5.93	70						
3-9.5.93	71						
10-16.5.93	72						

CHAPTER 3

EFFECT OF PULSES IN PHYTOPLANKTON PRODUCTION ON THE ABUNDANCE OF TASMANIAN BLENNY LARVAE, HATCHING DATE AND SETTLEMENT VARIABILITY AND RELATIONSHIP BETWEEN LARVAL SUPPLY AND SETTLEMENTS

3.1 INTRODUCTION

The massive settlement variability of post-larval marine invertebrates and fish both within and between years significantly affects the structure of adult populations (Connell, 1961; Cushing, 1975; Keough, 1983; Sale et al., 1984; Caffey, 1985; Doherty and Williams, 1988). This settlement variability is generally caused by variations in the planktonic environment affecting the distribution and survival of the larvae (Cushing, 1975; Lasker, 1981; Parrish et al., 1981; Houde, 1987).

Hjort's (1914, 1926) "critical period" concept suggested that catastrophic mortalities of fish larvae occur when planktonic food densities are low at the time of transition from the yolk-sac stage to active feeding so that the animals starve. Laboratory studies have shown that sufficiently high concentrations of planktonic food are crucial to successful first feeding and subsequent survival (O'Connell and Raymond, 1970; Laurence, 1974, 1977; Houde, 1974, 1977, 1978; Houde and Schecktere, 1978; Lasker and Zweifel, 1978; Mills, 1994).

Unfortunately, few field studies have demonstrated a critical period (Shelbourne, 1957; Lasker, 1975). Crisp (1954) thought that the breeding cycles of fish were regulated so that their larval progeny hatch at a time favourable for finding food, a strategy that should help these animals survive a critical period of their lives. Cushing (1967) reported that variations in the spawning times of herring (*Clupea harengus* L.) populations in the northeast Atlantic were linked to variations in primary production. However, Cushing (1970) pointed out that the hatching of fish larvae may not always correspond with the availability of suitable food because of variations in the timing of seasonal plankton blooms. Stocks would be vulnerable to variations in the production cycle if the spawning

strategy depended for its success on larvae beginning to feed at the height of planktonic food production (Cushing, 1970). If so, the timing of a plankton bloom in relation to the timing of larval fish production may be critical to the success of a year class (Cushing, 1970; Wyatt, 1972; May, 1974).

The timing of both peak spawning activity of fish and the spring phytoplankton bloom may vary by several weeks from year to year, but is not necessarily synchronised (Cushing, 1975). For optimal first feeding, reproductive strategies of fish should reflect the mean seasonal pattern of peaks in phytoplankton production resulting in zooplankton blooms (Townsend, 1983). Variation in the relative timing of spawning and seasonal plankton blooms could be a major determinant of interannual variability in survival. Cushing (1975) referred to his elaboration of Hjort's 'critical period' hypothesis as the 'match/mismatch theory'.

The spawning times for many Australian marine fishes are well known. It is therefore possible to predict the occurrence of larvae from these species with some accuracy, although the link with seasonal pulses of production has yet to be examined in detail. A recent investigation on the settlement of larval clinids *Heteroclinus* spp. in the Derwent Estuary in Tasmania found that episodic settlements were invariably preceded by brief, irregularly occurring pulses in phytoplankton production (Thresher et al., 1989). This finding supports the existence of a 'critical period' when settlement rates are determined by the availability of food for new-born larvae. Thresher et al. (1989) suggested that short-term transients of nutrient enrichment could underlie the extreme temporal patchiness of settlement by marine organisms and may have profound effects on their population ecology.

This investigation was undertaken to determine the effect of pulses in phytoplankton production (chlorophyll-a concentration) on the abundance and settlement of Tasmanian blenny larvae. The link between the abundance of larvae and the number of newly settled blennies was also assessed.

3.2 MATERIALS AND METHODS

3.2.1 Sampling Site

The sampling site was at Taroona, in Storm Bay, as described in Chapter 2, section 2.2.

3.2.2 Field Sampling

3.2.2.1 Larval Fish Sampling

Sampling of larval fish was done weekly during spring/summer in 1992-93 and 1993-94 as described in Chapter 2, section 2.3.1.

3.2.2.2 Sampling of Newly Settled Juveniles

Newly settled juveniles were collected during spring/summer in consecutive years between 1992 and 1995 as described in Chapter 2, section 2.3.2.

3.2.2.3 Water Quality (Chlorophyll-a and Nutrients)

Discrete water samples for the analysis of chlorophyll-a and nutrients were collected weekly from a depth of 10 m on the same day and at the same site as the larval fish were sampled. Water was collected in 8 L PVC Niskin bottles. Water samples for chlorophyll-a analysis were stored in 10 L carboys, which had been acid-washed and seawater-conditioned, then processed in the laboratory within 3 hours of collection. Water samples used to measure nutrient levels were filtered through 0.45 μ nucleopore membrane in a 25 mm Swin-Lok Filter Holder and were stored in high-density polyethylene bottles at -20°C for later analysis. In 1994-95 water samples were collected fortnightly from a depth of 10 m.

3.2.3 Laboratory Analysis

3.2.3.1 Water Quality Analysis

All chemicals used were of at least analytical reagent grade (Analar). Water for washing glassware and preparing reagents was from a Millipore

Milli-RO/Milli-Q system (MQ water). All glassware and sample bottles were washed in 10% HCl solution and rinsed three times with MQ water.

3.2.3.1.1 Chlorophyll Determinations

Chlorophyll-a concentration was measured using the acetone extraction (Trichlometric Chlorophyll determination) method of Jones (1979).

3.2.3.1.2 Nutrients

Nitrate and phosphate analyses were based on the automated analysis of nutrients in sea water that has been recommended in Airey and Sandars (1987).

3.2.3.2 Otolith Analysis

Preparation, examining and aging of otoliths was described in Chapter 2, section 2.4.3. Back-calculation of hatching and settlement dates of *P. t. tasmanianus* that survived until the time of sampling was described in Chapter 2, section 2.4.3.3.

3.2.4 Statistical Analysis

A correlation matrix was used for analysing the relationship between several variables. The numeric data were ln (x + 1) transformed prior to ensure homoscedasticity. Sampling noise was reduced by analysing data as moving averages over 3 adjacent points. Kruskal-Wallis's test was used to test the difference between two or more factors if data were not normally distributed and were considered to be statistically significant if $P < 0.001$. The statistical package was described in chapter 2, section 2.5.

3.3 RESULTS

3.3.1 The Concentration of Phytoplankton Production (Chlorophyll-a)

Phytoplankton production, as measured by chlorophyll-a, was higher in 1993-94 than in either 1992-93 or 1994-95 (Table 3.1). The seasonal pattern of water column production differed between years ($P < 0.001$), with an early peak in the summer of 1992-93; two mid-season peak in 1993-94 and a mid-season peak in 1994-95 (Fig. 3.8).

3.3.2 The Concentration of Nitrate and Phosphate

The temporal pattern of variation in nitrate concentration differed markedly between years (Fig. 3.1), whereas phosphate levels were generally low and fluctuated only slightly (Fig. 3.1). For both nutrients, there was no consistent relationship between nutrient levels and chlorophyll-a concentrations, at any reasonable lag (up to 6 w), when the data were summed over years (Table 3.2). In some years (e.g., 1992-93), there were significant correlations between nutrients and chlorophyll levels (Table 3.3), but given the lack of consistency, this relationship seems doubtful. In 1994-95, no statistical analysis was conducted due to small sample size.

3.3.3 The Abundance of Tasmanian Blenny Larvae

Larvae of *P. t. tasmanianus* constituted 1.31% and 1.71% of total larval catches in 1992-93 and 1993-94, respectively. A total of 46 blenny larvae were caught in 1992-93, whereas 206 blenny larvae were sampled in 1993-94. As reported earlier in comparison of larval sampling technique (chapter 2, section 2.3.2), the water volume filtered through the 1 m ring net, used in 1992-93, was significantly higher than that filtered through a pair of 50 cm bongo nets (mean water volume filtered through the ring net was 362.95 m^3 versus 103.1 m^3 for the bongo nets). Therefore the number of larvae collected each year was adjusted to a standardized per 250 m^3 of water filtered. Based on this adjustment, the adjusted total number of blenny larvae caught in 1992-93 was 0.52 larvae per sample, as compared with 3.39 larvae per sample for 1993-94. The difference between years is significant at $P < 0.0001$.

Table 3.1 Range and average of chlorophyll a, nitrate and phosphate measured in Derwent Estuary during spring/summer in 1992-93, 1993-94 and 1994-95.

	Year 1992-93			Year 1993-94			Year 1994-95		
	Range	Average	S.D.	Range	Average	S.D.	Range	Average	S.D.
Chlorophyll a (μg/L)	0.71-3.21	1.36	0.73	1.25-3.81	2.17	0.83	0.92-3.15	1.83	0.79
Nitrate (μM/L)	0.2-2.2	0.57	0.60	0-2.2	0.53	0.59	0.1-0.2	0.17	0.05
Phosphate (μM/L)	0.26-0.60	0.36	0.10	0.21-0.55	0.32	0.09	0.21-0.34	0.28	0.05

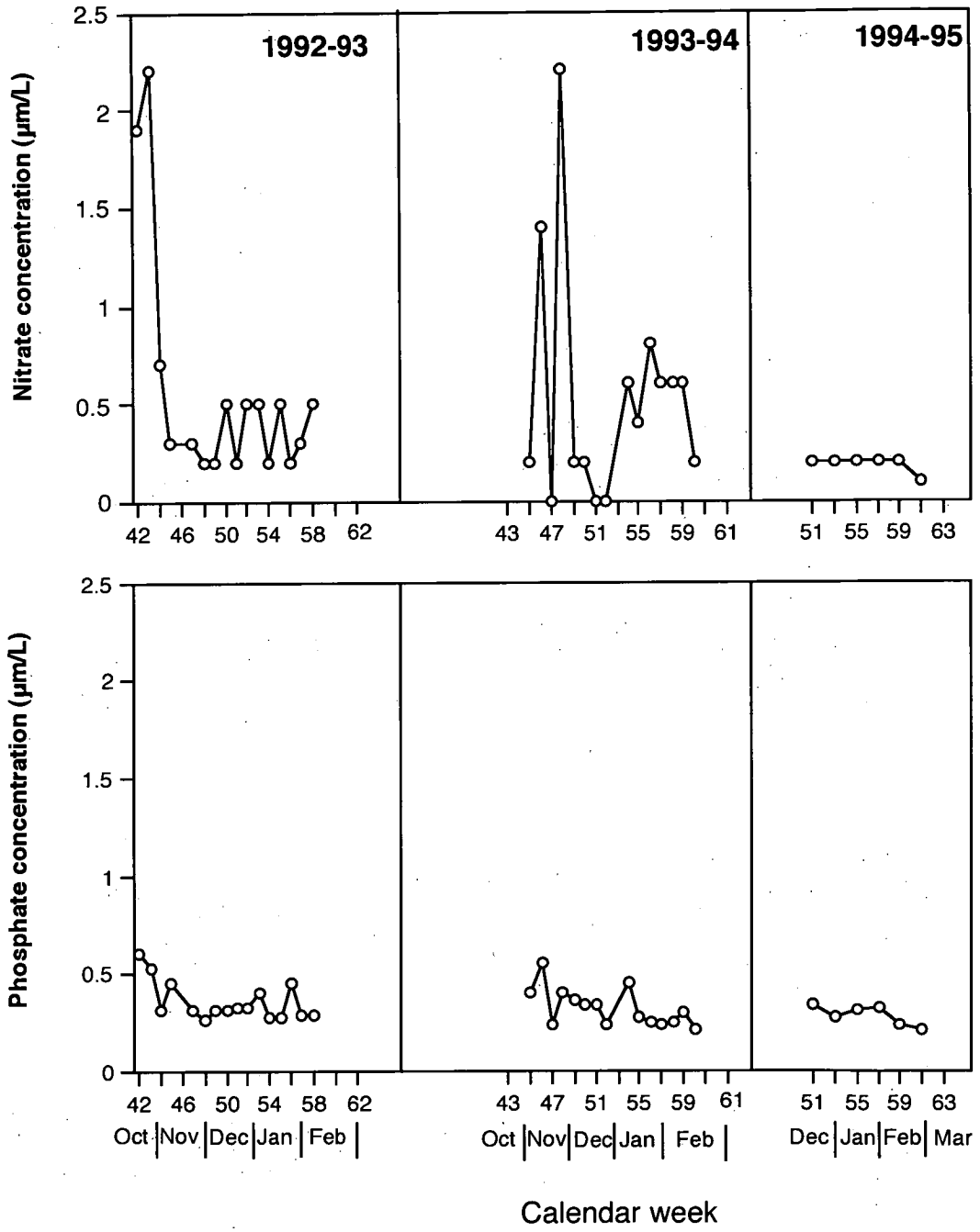

Figure 3.1. Record of nitrate (top) and phosphate (bottom) measured at 10 m depth during spring/summer from 1992-93 to 1994-95.

Table 3.2 R^2 and r value (correlation) between nutrients and chlorophyll-a concentrations at weeks lag when weeks were summed over years. Number in the first row correspond to week ago. (** P < .001, *** P < .0001, n = 21)

Nutrients	0	1	2	3	4	5	6
nitrate	r = 0.24	r = 0.26	r = 0.26	r = 0.27	r = 0.3	r = 0.32	r = 0.28
	R^2 = 0.06	R^2 = 0.07	R^2 = 0.07	R^2 = 0.07	R^2 = 0.09	R^2 = 0.10	R^2 = 0.08
phosphate	r = -0.10	r = -0.28	r = -0.79***	r = -0.71	r = -0.64**	r = -0.43	r = -0.12
	R^2 = 0.01	R^2 = 0.08	R^2 = 0.62	R^2 = 0.51**	R^2 = 0.42	R^2 = 0.19	R^2 = 0.01

Table 3.3 R^2 and r value (correlation) between nutrients and chlorophyll-a concentrations at weeks lag within years. Number in the first row correspond to week ago. (* P < .01, *** P < .0001)

Year	Nutrients	0	1	2	3	4	5	6
1992-93	nitrate	r = -0.66	r = -0.82*	r = -0.79*	r = -0.79*	r = -0.55	r = 0.02	r = 0.56
		R^2 = 0.44	R^2 = 0.67	R^2 = 0.63	R^2 = 0.62	R^2 = 0.31	R^2 = 0.0005	R^2 = 0.32
	phosphate	r = -0.25	r = -0.62	r = -0.82*	r = -0.90***	r = -0.75*	r = -0.18	r = 0.25
		R^2 = 0.06	R^2 = 0.39	R^2 = 0.67	R^2 = 0.81	R^2 = 0.56	R^2 = 0.03	R^2 = 0.06
1993-94	nitrate	r = 0.40	r = 0.56	r = 0.58	r = 0.69	r = 0.58	r = 0.51	r = 0.44
		R^2 = 0.16	R^2 = 0.32	R^2 = 0.34	R^2 = 0.48	R^2 = 0.34	R^2 = 0.26	R^2 = 0.19
	phosphate	r = 0.45	r = 0.12	r = -0.83*	r = -0.64	r = -0.56	r = -0.56	r = -0.54
		R^2 = 0.20	R^2 = 0.01	R^2 = 0.70	R^2 = 0.42	R^2 = 0.32	R^2 = 0.32	R^2 = 0.29

The temporal pattern of variation in larval abundance (by calendar week; see chapter 2, section 2.6) is shown in Fig. 3.2. In 1992-93, larvae caught at the surface were significantly fewer than the subsurface tows ($P < 0.001$). There was also large difference in catch rates seasonally (differences between weeks, $P < 0.0001$, ANOVA), but no interaction between week and tow type ($P > 0.05$, ANOVA) was found. Overall seasonal patterns of larval abundance, as measured by surface and subsurface tows, were similar.

In 1993-94, the number of larvae caught by surface and subsurface tows did not differ significantly ($P > 0.05$, ANOVA), nor was there a significant interaction between week and tow type ($P > 0.05$, ANOVA) which suggests this pattern was consistent throughout the sampling period. There was a conspicuous difference between the number of larvae collected each week, however ($P < 0.001$). Peaks in larval abundance occurred on week 50, week 55, and week 59. There were still low numbers of larvae present at the end of sampling (Fig. 3.2).

3.3.4 Length-Frequency Distribution of Tasmanian Blenny Larvae

Almost all larvae caught in both years were preflexion with only one flexion larva caught in 1992-93 (week 53) and one in 1993-94 (week 50) (Table 3.4 and 3.5). This suggests that new larvae were being produced throughout the sampling period. The length-frequency distribution seems to indicate high mortality or transport of some cohorts, as the larger size categories were missing from some samples, especially during the last collecting trips (Table 3.4 and 3.5).

In 1992-93, the mean size of larvae collected during surface and subsurface tows differed significantly ($P < 0.01$), with larvae from subsurface tows generally larger than those collected at the surface. Larvae at the surface ranged in length from 3.0 to 4.8 mm SL (mean = 3.7 mm, S.D. = 0.53), whereas those in subsurface tows ranged from 3.3 to 7.4 mm SL (mean = 4.2 mm, S.D. = 0.88) (Fig. 3.3). The mean length of larvae collected by surface tows did not differ throughout the sampling period ($P > 0.05$). There was a significant seasonal difference between the mean lengths of larvae from subsurface tows ($P < 0.01$), but this was largely due to the presence of a very large larvae (7.4 mm SL) collected in week 53. Excluding this larva from the analysis resulted in a non-significant seasonal term.

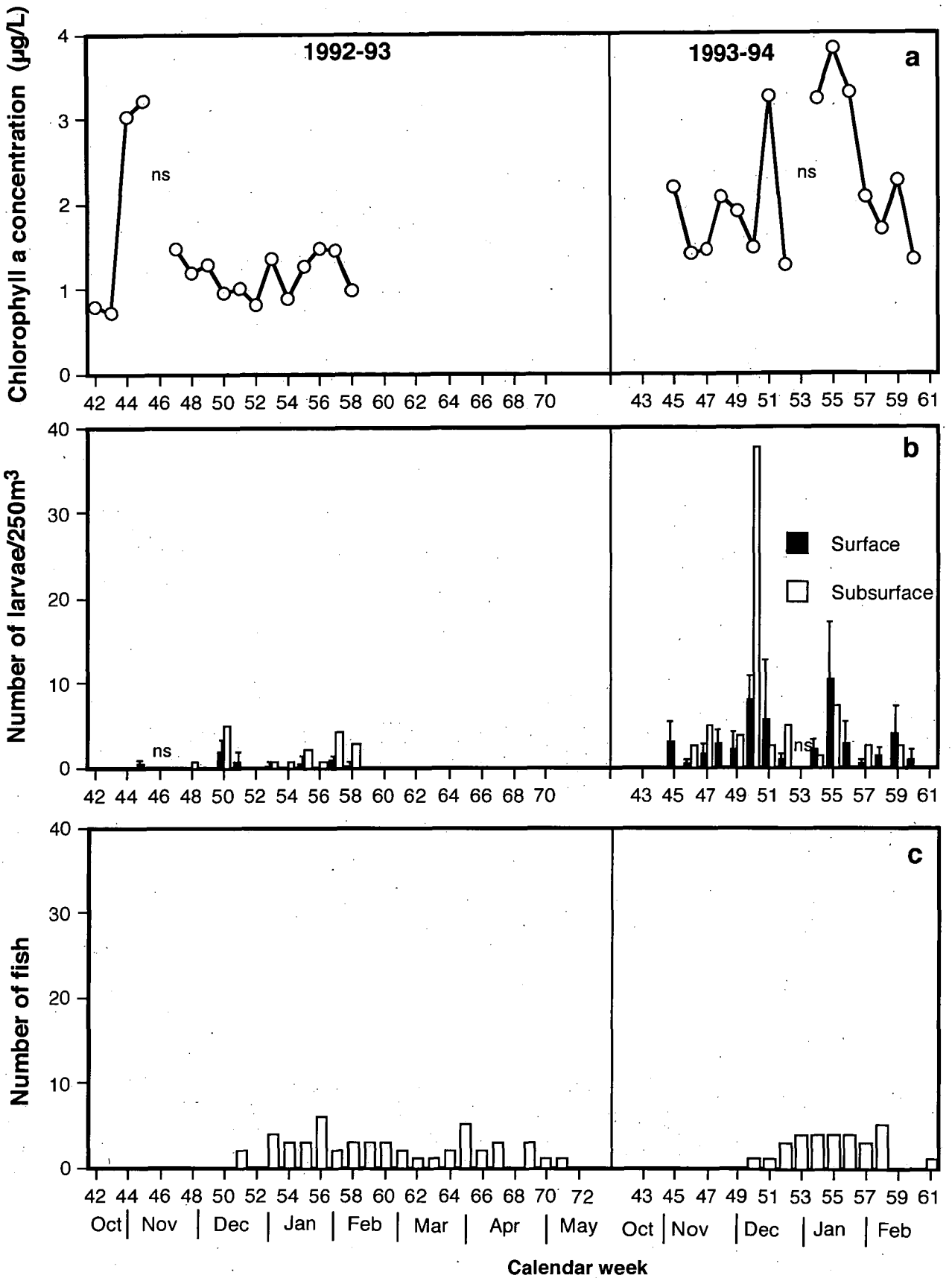

Figure 3.2. a. Chlorophyll-a concentration measured at 10 m depth.
b. Abundance of larvae (Bars = means; vertical lines = ranges of sample).
c. Back-calculation settlement dates (as determined from otoliths of juveniles) aggregated by calendar week; ns = no sampling.

Table 3.4 Length-frequency of *P. t. tasmanianus* larvae caught during October 1992 to February 1993 from Storm Bay 'Taroona sampling site'. The numbers of larvae in each mm interval are given as well as the mean and standard deviation for each sampling date.

Date	Standard length (mm)								
	3.0-4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0	Total	Range	mean	S.D.
12.10.92 (week 42)									
19.10.92 (week 43)									
26.10.92 (week 44)									
2.11.92 (week 45)	2					2	3.1-3.5	3.3	0.3
16.11.92 (week 47)									
24.11.92 (week 48)		1				1	4.7		
30.11.92 (week 49)									
7.12.92 (week 50)	8	6	1			15	3.2-5.2	4.0	0.61
15.12.92 (week 51)		3				3	4.1-4.6	4.3	0.26
21.12.92 (week 52)	1					1	4.0		
30.12.92 (week 53)	1				1	2	3.8-7.4	5.6	2.54
5.1.93 (week 54)	1					1	3.3		
11.1.93 (week 55)	3	2				5	3.4-4.2	3.7	0.38
18.1.93 (week 56)	1					1	3.6		
25.1.93 (week 57)	7	3				10	3.0-4.7	3.7	0.61
3.2.93 (week 58)	1	3	1			5	3.4-5.6	4.4	0.79
Total of larvae	25	18	2		1	46	3.0-7.4	4.0	0.79

Table 3.5 Length-frequency of *P. t. tasmanianus* larvae caught during November 1993 to February 1994 from Storm Bay 'Taroona sampling site'. The numbers of larvae in each mm interval are given as well as the mean and standard deviation for each sampling date.

Date	Standard length (mm)								
	3.0-4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0	Total	Range	mean	S.D.
5.11.93 (week 45)	10					10	3.4-4.0	3.7	0.17
12.11.93 (week 46)		3				3	4.1-4.4	4.2	0.17
19.11.93 (week 47)	5	4				9	3.5-4.6	4.0	0.39
26.11.93 (week 48)	7	2				9	3.4-4.5	3.8	0.37
6.12.93 (week 49)	7	2	1			10	3.5-5.6	4.0	0.66
10.12.93 (week 50)	43	10	2	2		57	3.4-6.4	3.9	0.64
17.12.93 (week 51)	20					20	3.4-3.8	3.6	0.14
24.12.93 (week 52)	5	2				7	3.2-4.3	3.7	0.40
7.1.94 (week 54)	8					8	3.3-3.7	3.5	0.12
14.1.94 (week 55)	37	2				39	3.0-4.3	3.5	0.29
21.1.94 (week 56)	9					9	3.1-3.4	3.3	0.16
31.1.94 (week 57)	3					3	3.4-3.6	3.5	0.11
4.2.94 (week 58)	4					4	3.3-3.5	3.4	0.08
11.2.94 (week 59)	14	1				15	3.2-4.2	3.5	0.26
18.2.94 (week 60)	3					3	3.2-3.5	3.4	0.15
Total of larvae	175	26	3	2		206	3.0-6.4	3.7	0.48

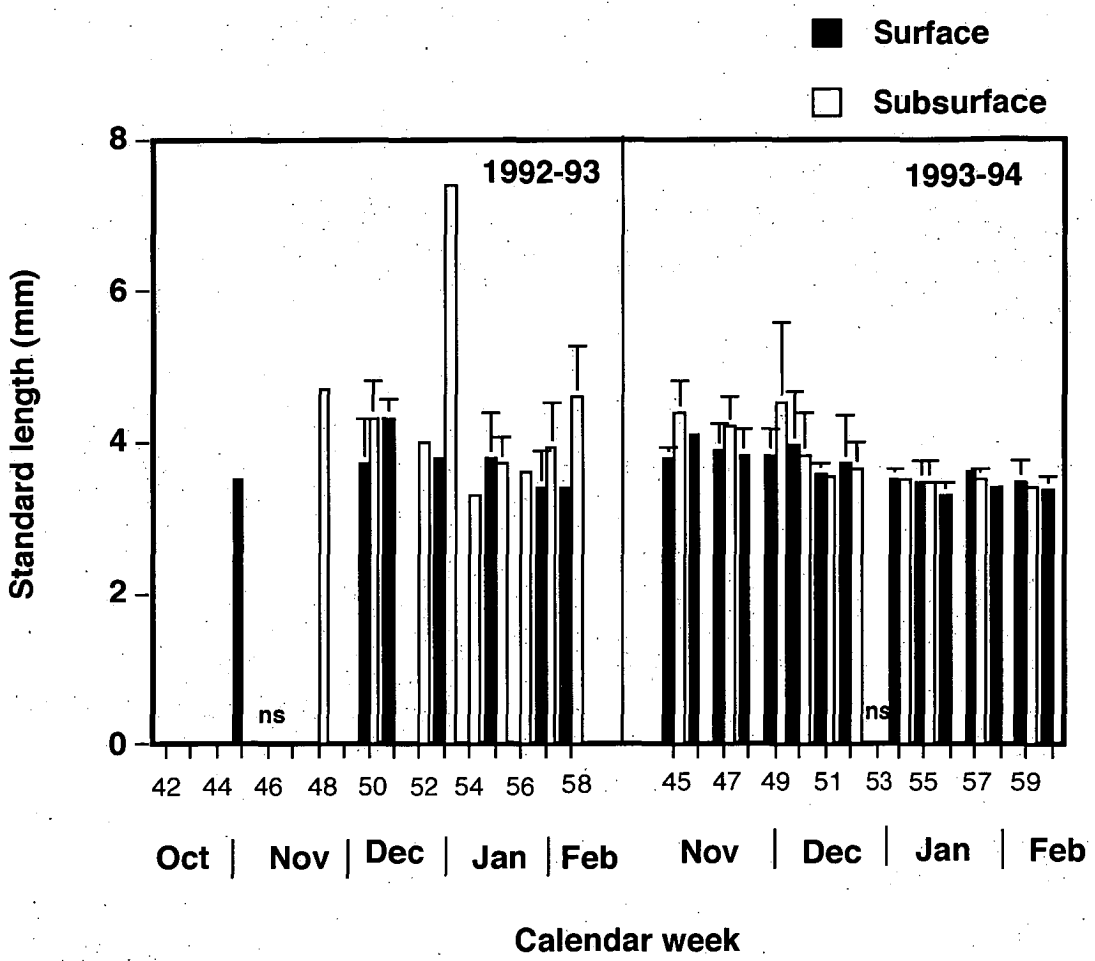

Figure 3.3. Length of Tasmanian blenny larvae collected by surface and subsurface tows during spring/summer sampling period in 1992-93 and 1993-94; Bar = mean, vertical line = range, ns = no sampling.

As in 1992-93, subsurface tows in 1993-94 caught larger larvae than surface tows (range = 3.4 - 6.3 mm, mean = 3.8, S.D. = 0.56, versus range = 3.0 - 6.4 mm SL, mean = 3.6, S.D. = 0.43; $P < 0.01$). Unlike the previous season, however, the length of larvae collected by both techniques declined significantly during the spawning season ($P < 0.0001$, for surface tows; $P < 0.05$ for subsurface tows, Fig. 3.4).

3.3.5 The Abundance of Newly Settled Juveniles

Biweekly variability in the number of blennies collected in 1992-93, 1993-94, 1994-95 at the Taroona site, separated into two size classes, are shown in Fig. 3.5. The number of newly settled Tasmanian blennies collected per sample varied widely. Although there was a difference in the magnitude of the settlement between years, the patterns of variation were similar. In 1992-93 (n = 51) and 1993-94 (n = 30), few newly settled blennies were caught, whereas large numbers were taken in 1994-95 (n = 127). Newly settled blennies were collected between the end of December and mid March with abundance in all years, peaking in mid January.

In 1992-93, few newly settled blennies were captured which may have resulted from late settlement, an additional sample was taken in May. Some newly settled juveniles appeared to be captured in May, though it is possible that these later fish were slow-growing juveniles that had recruited some months earlier.

3.3.6 Back-Calculation of Hatching and Settlement Dates

The duration of the planktonic larval stage, as determined from otolith analyses, differed significantly between years ($P < 0.0001$, Kruskal - Wallis Tests). In 1993-94, the larval period was longer than 1992-93 and 1994-95 (Fig. 3.6a). The planktonic larval duration varies seasonally from 36 to 69 days (mean = 46.3, S.D. = 6, n = 208), after which the fish settled in tide pools. The hatching dates were negatively correlated to larval duration for all three years ($P < 0.05$, Fig. 3.7). The size of newly settled *P. t. tasmanianus* ranged in length from 15.7 to 18.4 mm SL (mean = 17.3 ± 0.87), and did not vary seasonally ($P > 0.05$, Fig. 3.6b).

The distribution of back-calculated hatching dates, pooled by calendar week, are shown for all years in Fig. 3.8b. The temporal pattern of

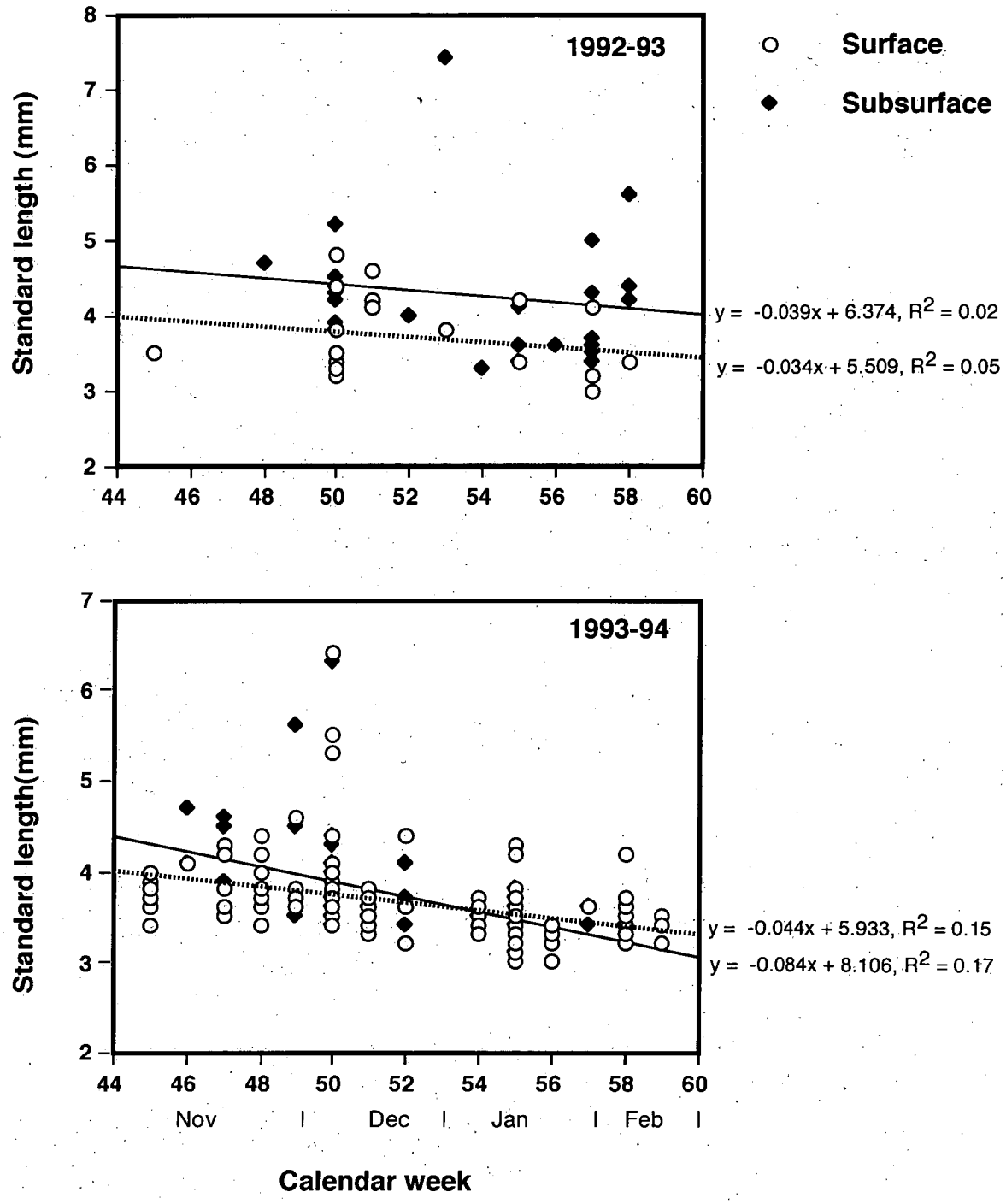

Figure 3. 4. Scatteplot of larval size versus capture week in 1992-93 (top) and 1993-94 (bottom). Plain line show regression for subsurface tows and dash line shows regression for surface tows.

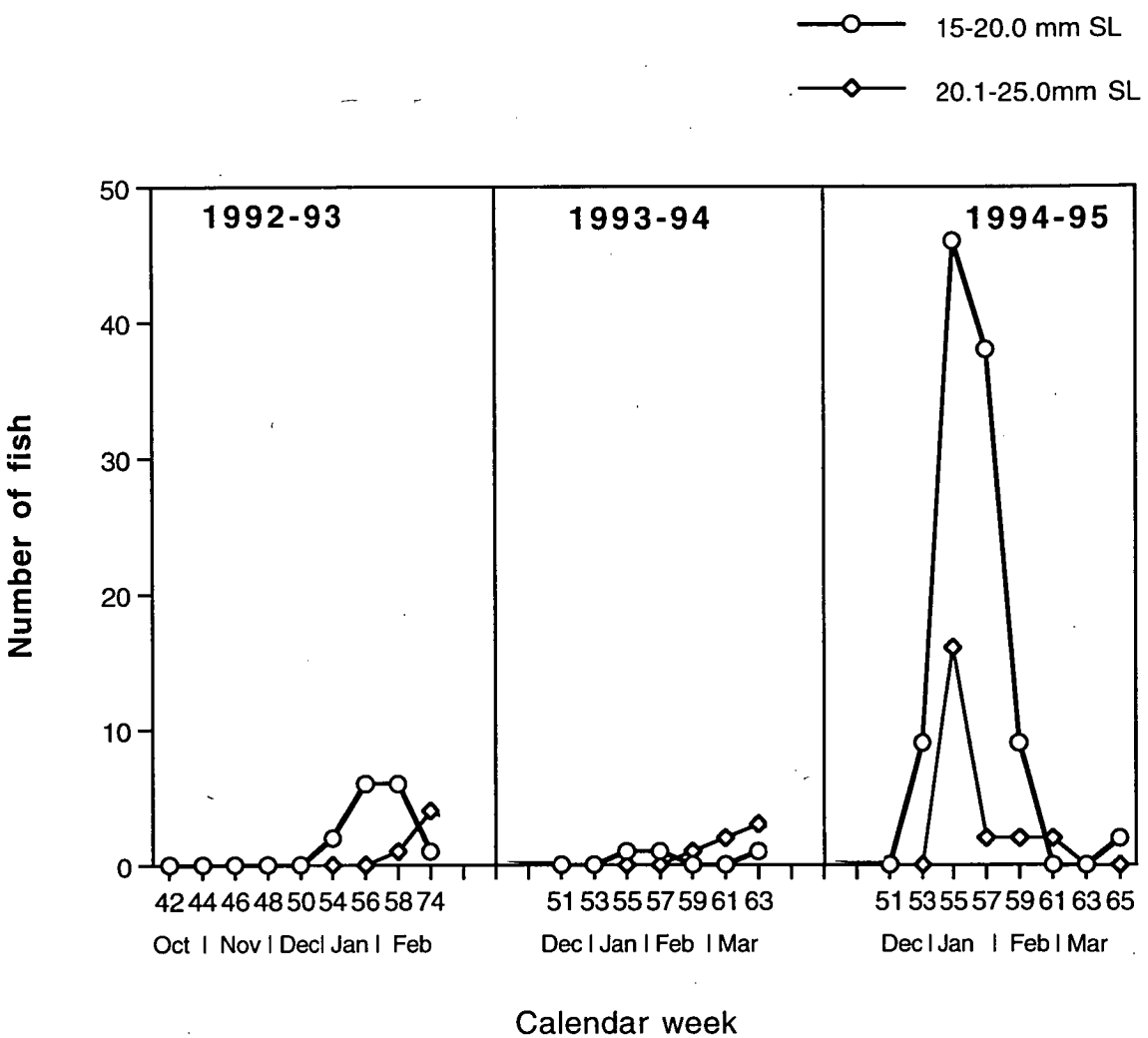

Figure 3.5. Number of blennies collected from tide pools at Taroona during spring/summer in 1992-93, 1993-94 and 1994-95.

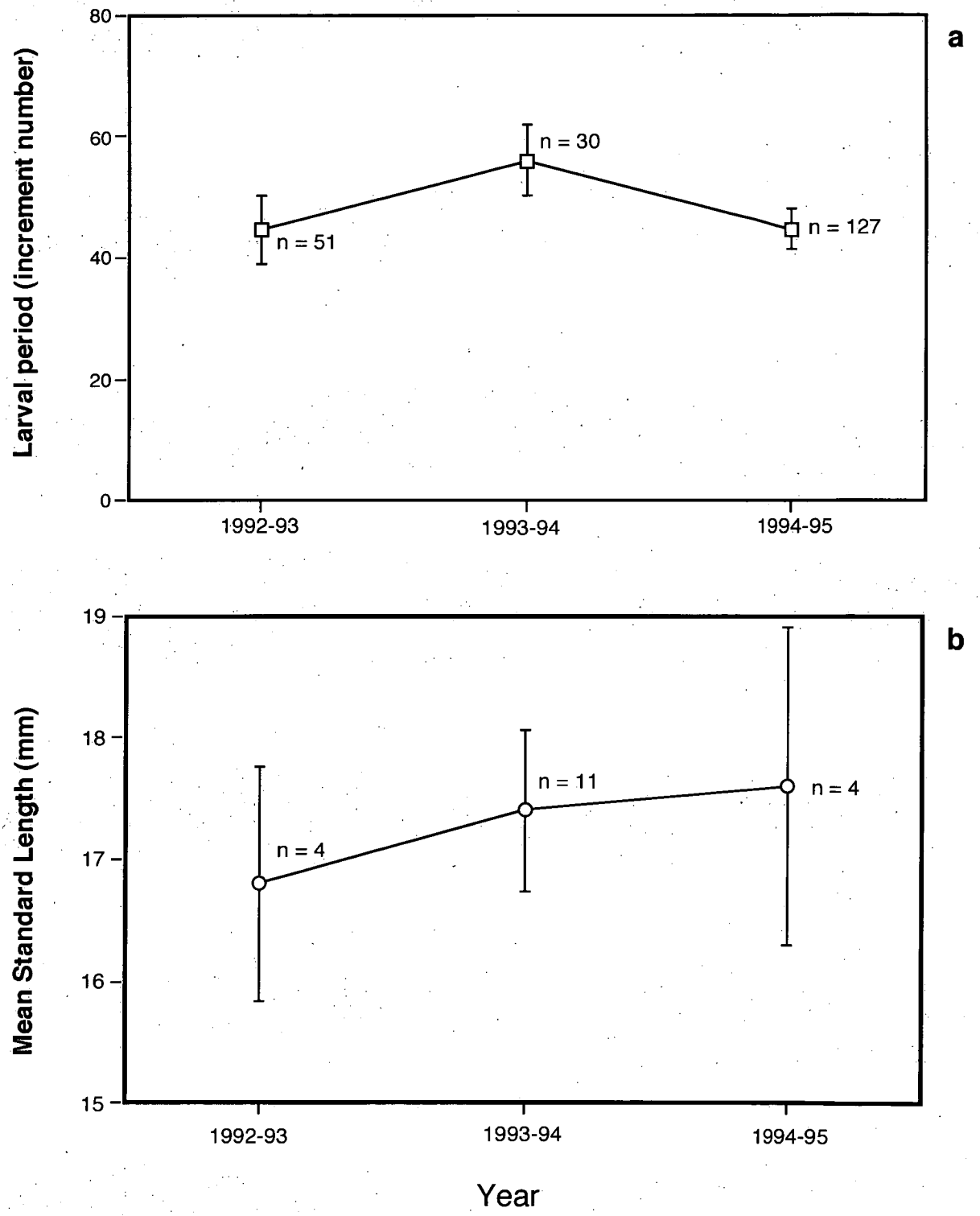

Figure 3.6. a. Larval period between years. b. size of newly settled juvenils between years (Vertical line indicates the range for each sample); n = sample size.

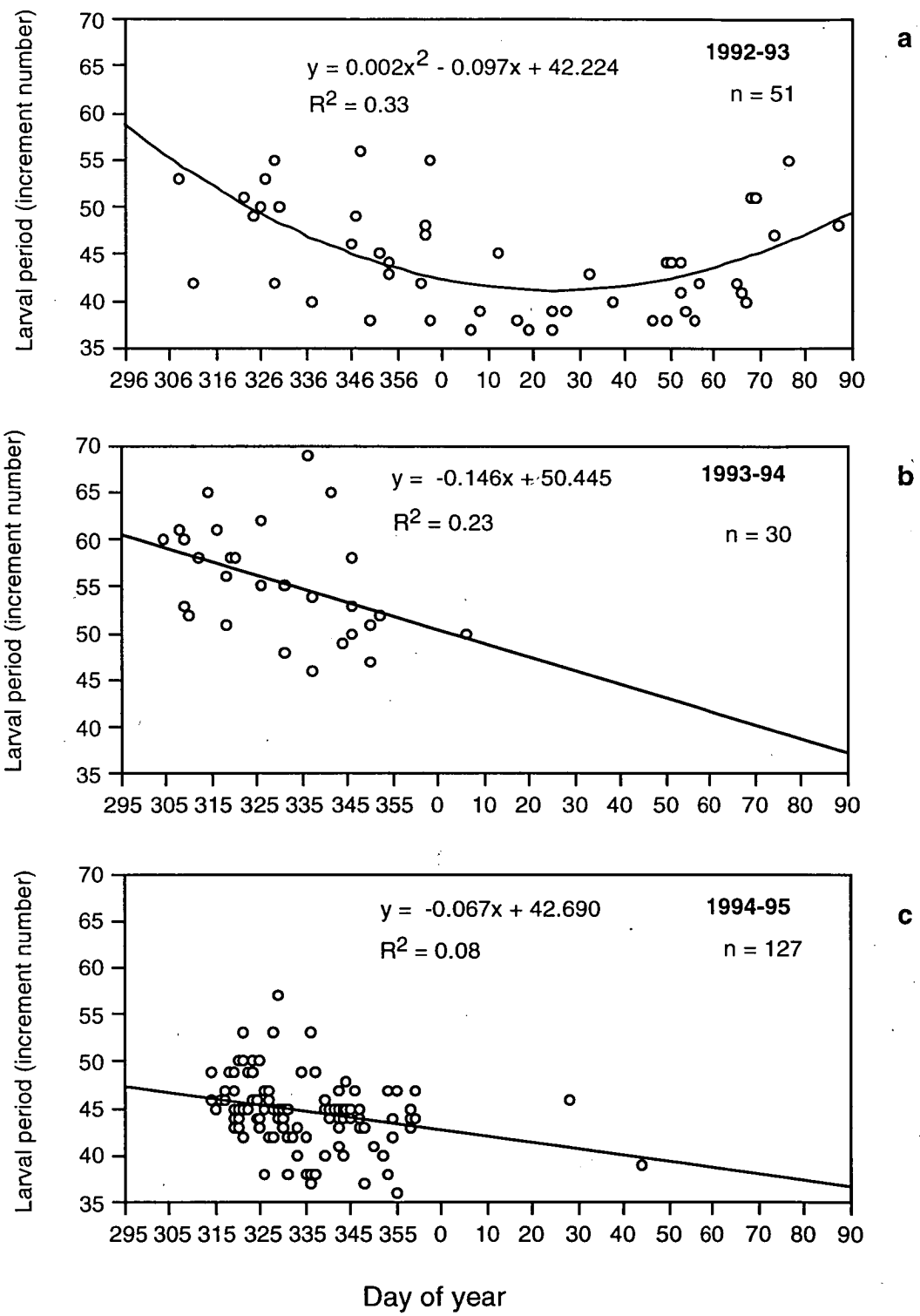

Figure 3.7. Regressions of hatching days against larval period of blennies in 1992-93 (a), 1993-94 (b), and 1994-95 (c).

hatching varied widely between years.

Settlement patterns, as deduced from otolith structure, for three years is shown in Fig. 3.8c. The pattern of temporal variation in settlement differed markedly between years, with a prolonged period of low settlement in 1992-93, a short (8 weeks) period of low settlement in 1993-94, and a large peak of settlement in 1994-95. The settlement in 1992-93 appeared to be prolonged through until mid May, although it is possible that these later fish were slow-growing juveniles that had recruited some months later irregularly throughout the sampling period.

3.3.7 The Relationship Between Pulses in Phytoplankton Production and the Abundance of Tasmanian Blenny Larvae

Pattern of chlorophyll-a concentration at 10 m depth, number of larvae and back-calculated settlement are shown in Fig. 3.9. No analyses could be conducted to assess the annual relationship between chlorophyll-a concentration and larval abundance due to small sample size (n = 2).

When week data were summed over year, there appeared to be positive correlation between abundance of larvae at the surface and chlorophyll-a concentration on the same week, for one w lag, and for 6 w lag (Table 3.6). However, larvae caught at subsurface were only correlated to chlorophyll-a concentration on the same week (Table 3.6).

The only positive correlation for individual years was at a lag of 6 w in 1992-93 found between the abundance of larvae at the surface and chlorophyll-a concentration (Table 3.7, Fig. 3.10). In other analyses, there were significant negative correlations between larvae and chlorophyll-a concentration, suggesting that this apparent statistical significance is not meaningful (Table 3.7).

3.3.8 The Relationships Between Pulses in Phytoplankton Production and Hatching Dates and Settlement Variability of Tasmanian Blenny

Patterns of chlorophyll-a concentration measured at 10 m depth, back-calculated hatching dates and back-calculated settlement are shown in Fig. 3.11. There were no analyses of relationship between chlorophyll-a

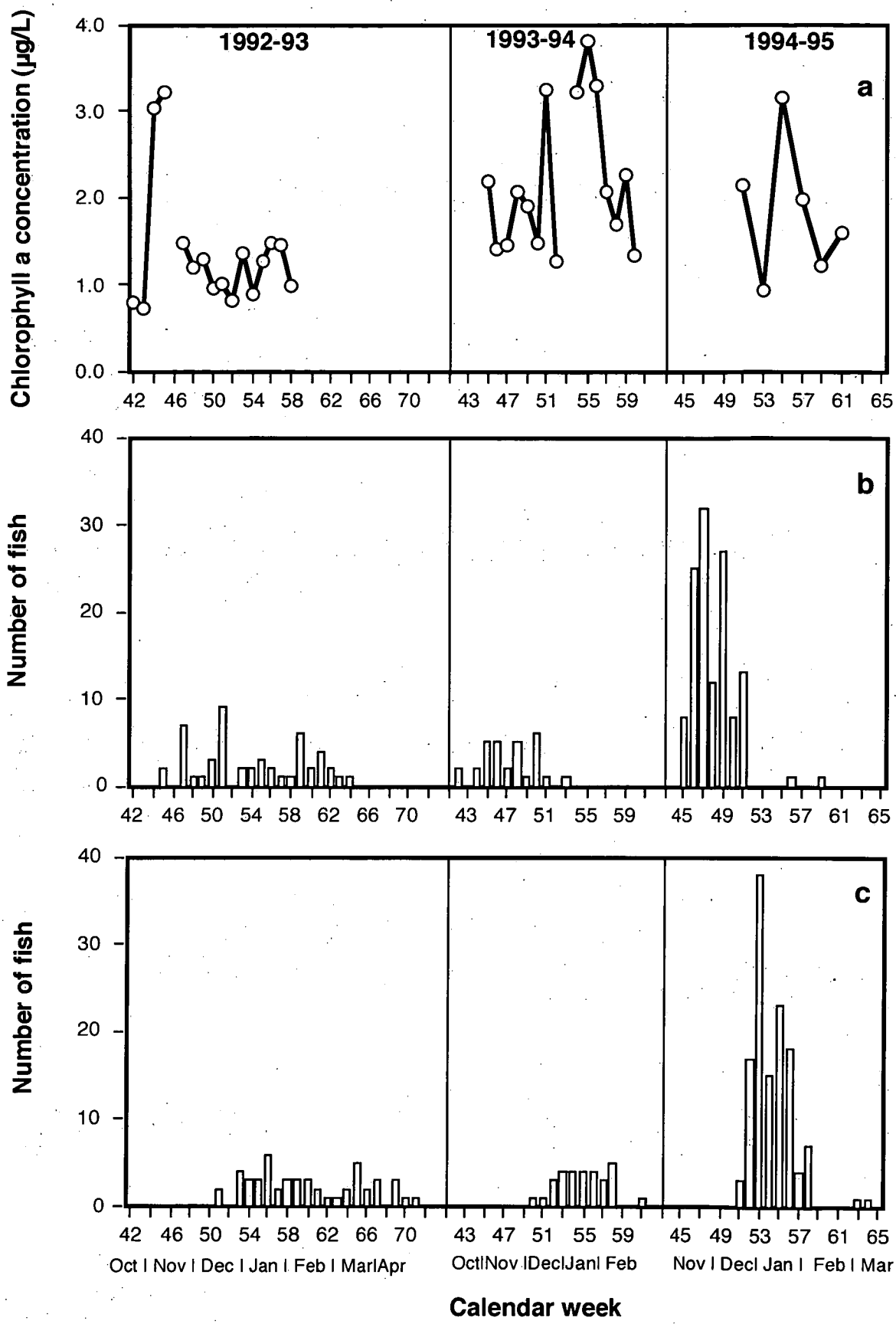

Figure 3.8. Pattern of chlorophyll-a concentration measured at 10 m depth (a) in relation to distribution of back-calculated hatching dates (b) and settlement dates (c), as determined from otoliths of juveniles, aggregated by calendar week. Data are for the period during spring/summer (October-March) from 1992 to 1995.

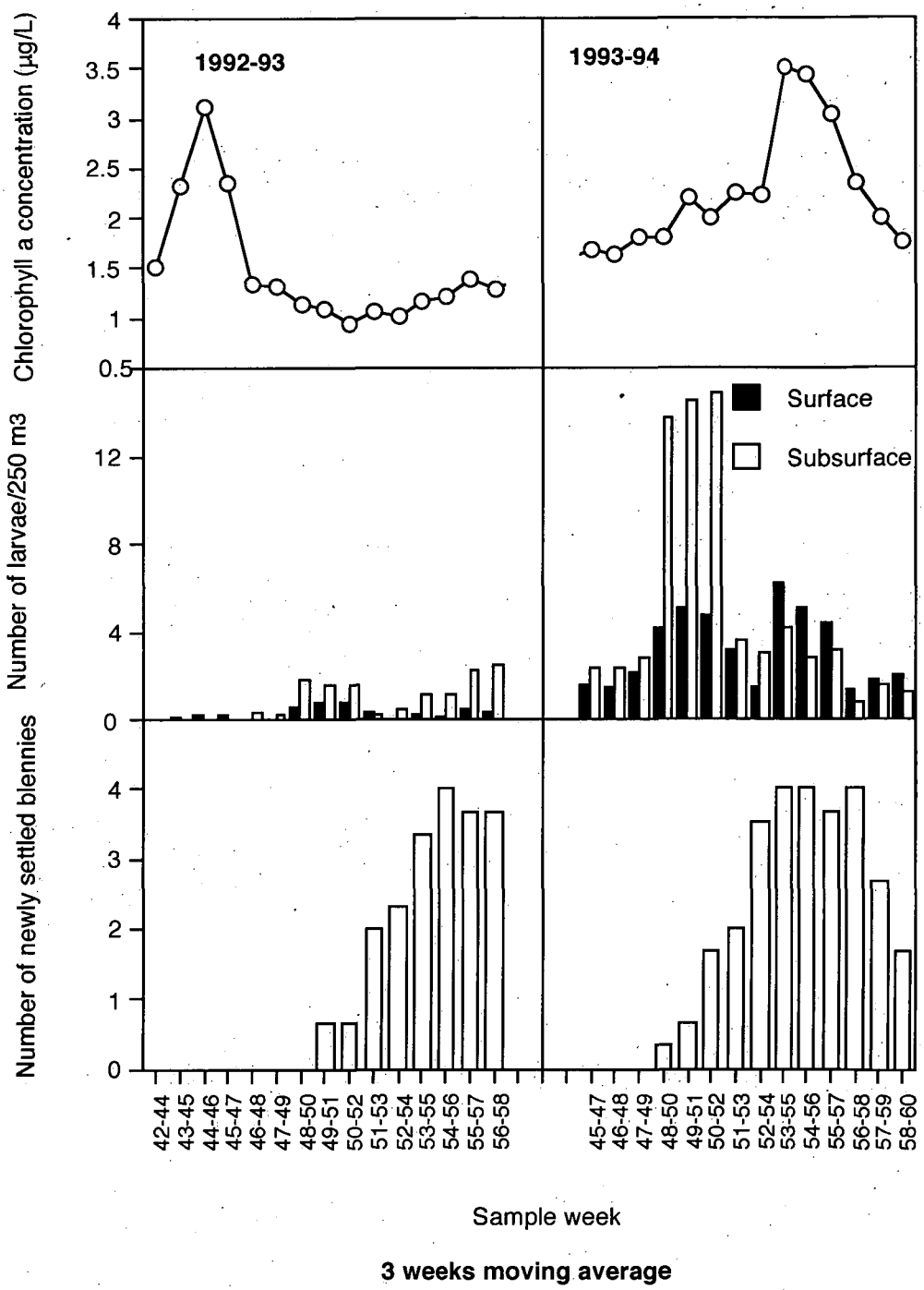

Figure 3.9. Pattern of chlorophyll-a concentration (top), number of larvae/250 m3 (middle) and number of back-calculated settlement, as determined from otoliths of blenny juveniles, (bottom) from data averaged 3 adjacent points.

Table 3.6 R^2 and r value (correlation) of the relationship between chlorophyll-a concentration and larvae at weeks lag when weeks were averaged over year. Number in first row correspond to week ago. (* P < .01, ** P < .001, *** P < .0001)

Larvae	0	1	2	3	4	5	6
surface	r = 0.79***	r = 0.75***	r = 0.26	r = 0.16	r = 0.34	r = 0.46	r = 0.61*
	R^2 = 0.62	R^2 = 0.56	R^2 = 0.07	R^2 = 0.03	R^2 = 0.11	R^2 = 0.21	R^2 = 0.37
subsurface	r = 0.54*	r = 0.48	r = 0.0002	r = -0.14	r = 0.0053	r = 0.13	r = 0.27
	R^2 = 0.29	R^2 = 0.23	R^2 = 0.0	R^2 = 0.02	R^2 = 0.00	R^2 = 0.02	R^2 = 0.07

Table 3.7 R^2 and r value (correlation) of the relationship between chlorophyll-a concentration and larvae at week lag within year. Number in first row correspond to week ago. (* P < .01, ** P < .001, *** P < .0001)

Year	Larvae	0	1	2	3	4	5	6
1992-93	surface	r = -0.45	r = -0.33	r = -0.57	r = -0.55	r = 0.07	r = 0.64	r = 0.69*
		R^2 = 0.20	R^2 = 0.11	R^2 = 0.33	R^2 = 0.30	R^2 = 0.005	R^2 = 0.41	R^2 = 0.47
	suburface	r = 0.02	r = 0.13	r = -0.44	r = -0.47	r = -0.08	r = 0.28	r = 0.14
		R^2 = 0.0005	R^2 = 0.02	R^2 = 0.19	R^2 = 0.22	R^2 = 0.01	R^2 = 0.08	R^2 = 0.02
1993-94	surface	r = 0.58	r = 0.02	r = -0.33	r = -0.81*	r = -0.41	r = -0.37	r = -0.07
		R^2 = 0.34	R^2 = 0.0004	R^2 = 0.11	R^2 = 0.66	R^2 = 0.17	R^2 = 0.12	R^2 = 0.005
	subsurface	r = 0.04	r = -0.34	r = -0.52	r = -0.89**	r = -0.64	r = -0.59	r = -0.25
		R^2 = 0.002	R^2 = 0.12	R^2 = 0.27	R^2 = 0.80	R^2 = 0.42	R^2 = 0.35	R^2 = 0.06

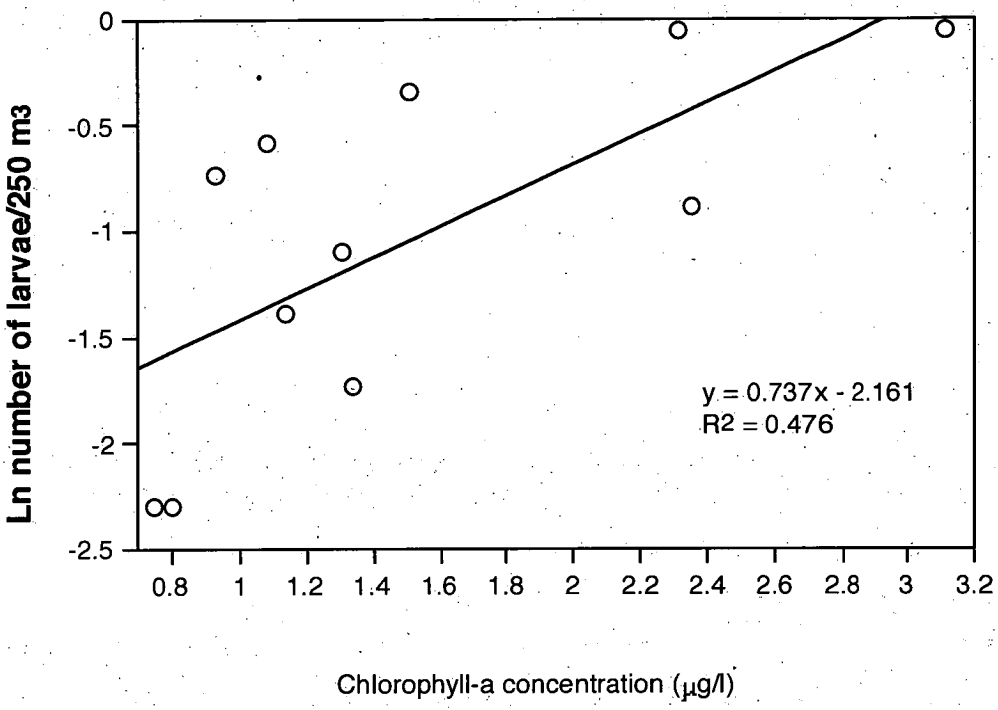

Figure 3.10. Regression of chlorophyll-a concentration against ln number of larvae/250 m 3 caught at surface at a lag of 6 w in 1992-93.

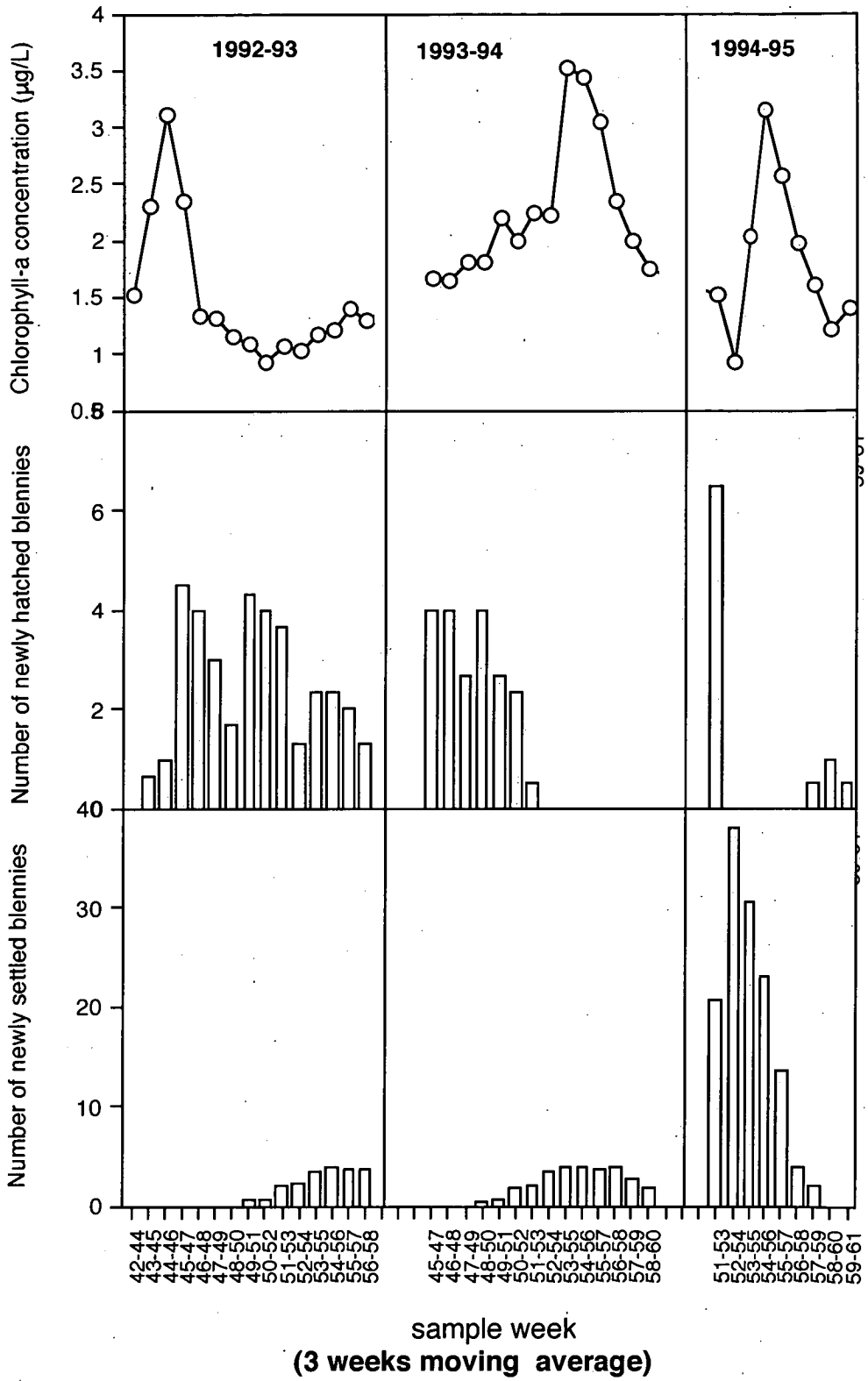

Figure 3.11. Pattern of chlorophyll-a concentration (Top), number of newly hatched blennies (middle), and number of newly settled blennies determined from otoliths of juveniles (bottom) from data moving average over 3 adjacent points.

concentration and number of newly hatched blennies and number of newly settled blennies when data were averaged by years due to small sample size (n = 3). When the data were pooled across years, there was no consistent relationship between chlorophyll-a concentration and the number of newly hatched blennies nor the number of newly settled blennies at any reasonable lag (up to 4 w for hatching time and up to 14 w for settlement date) (Table 3.8).

Within years, there was no consistent relationship between chlorophyll-a concentration and the number of back-calculated hatching blennies found in each of the three years (Table 3.9), but number of newly settled blennies were correlated with chlorophyll concentration at lags of 11 and 12 w in 1992-93 and at lags of 0 and 1 and 2 w in 1993-94 (Table 3.9, Fig. 3.12 and 3.13). In 1994-95, there was no hatching on the same week as chlorophyll peaks or at any reasonable lags up to 6 w and there was no settlement at lags of 7 to 14 w. There was no consistent correlation in 1994-95 (Table 3.9).

There were also negative relationships between chlorophyll-a concentration and both number of newly hatched blennies and number of newly settled blennies at reasonable lag (up to 4 w for hatching and 14 w for settlement) when data were summed over years and also for data within years (Table 3.8 and 3.9).

3.3.9 The Relationship Between the Abundance of Larvae and Number of Newly Settled Juveniles

Pattern of larvae and settlement when data were 3 weeks moving averaged are shown in Fig. 3.9. There was no consistent correlation between number of larvae (surface and subsurface), number of back-calculated newly settled blennies, and number of back-calculated newly hatched blennies when data were summed over years. (Table 3.10).

Within 1992-93, there was only a consistent relationship between number of larvae at the surface and the number of back-calculated newly hatched blennies at a lag of 1 w (Table 3.11). In 1993-94, there were consistent correlations between number of newly settled blennies and the number of larvae caught at the surface at lags of 2 and 3 w and between the number of larvae collected by subsurface tows at lags of 3 to 6 w (Table 3.11, Fig. 3.14 and 3.15). These relationships appeared to be strongly non-linear, and driven by poor settlement following periods of low larval numbers.

Table 3.8 R2 and r value (correlation) of the relationship between chlorophyll a concentration at week lag and back-calculated hatching date and back-calculated settlement date when weeks were averaged over years. Number in the first row corresponded to week lag. (* P < .01, ** P < .001, *** P < .0001).

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Hatching	r = -0.41* R^2 = .17	r = -0.45* R^2 = .20	r = -0.28 R^2 = .08	r = -0.40* R^2 = .16	r = -0.35 R^2 = .12										
Settlement	r = 0.01 R^2 = 0.0002	r = 0.15 R^2 = 0.02	r = -0.07 R^2 = 0.005	r = -0.12 R^2 = 0.01	r = -0.40* R^2 = 0.16	r = -0.59*** R^2 = 0.35	r = -0.32 R^2 = 0.10	r = -0.39* R^2 = 0.15	r = -0.32 R^2 = 0.11	r = -0.26 R^2 = 0.07	r = -0.37 R^2 = 0.14	r = -0.24 R^2 = 0.05	r = -0.31 R^2 = 0.09	r = -0.37 R^2 = 0.14	r = -0.36 R^2 = 0.13

Table 3.9 R2 and r value (correlation) of the relationship between chlorophyll a concentration at week lag and back-calculated hatching date and back-calculated settlement date within years. Number in the first row corresponded to week lag. (* P < .01, ** P < .001, *** P < .0001)

Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1992-93	Hatching	r = -0.30 R^2 = 0.09	r = -0.66* R^2 = 0.44	r = 0.33 R^2 = 0.11	r = 0.21 R^2 = 0.04	r = 0.17 R^2 = 0.03										
	Settlement	r = -0.39 R^2 = 0.16	r = -0.61* R^2 = 0.38	r = -0.77** R^2 = 0.60	r = -0.84*** R^2 = 0.71	r = -0.84*** R^2 = 0.71	r = -0.89*** R^2 = 0.80	r = -0.54 R^2 = 0.30	r = -0.64* R^2 = 0.40	r = -0.09 R^2 = 0.01	r = 0.44 R^2 = 0.20	r = 0.47 R^2 = 0.23	r = 0.82*** R^2 = 0.68	r = 0.57** R^2 = 0.33	r = 0.33 R^2 = 0.11	r = 0.26 R^2 = 0.06
1993-94	Hatching	r = -0.65* R^2 = 0.42	r = -0.62* R^2 = 0.39	r = -0.64* R^2 = 0.40	r = -0.58 R^2 = 0.34	r = -0.54 R^2 = 0.29										
	Settlement	r = 0.82** R^2 = 0.68	r = 0.82** R^2 = 0.68	r = 0.69* R^2 = 0.46	r = 0.45 R^2 = 0.21	r = 0.03 R^2 = 0.001	r = -0.49 R^2 = 0.24	r = - 0.52 R^2 = 0.27	r = -0.58 R^2 = 0.34	r = -0.64* R^2 = 0.42	r = -0.64* R^2 = 0.41	r = -0.63* R^2 = 0.39	r = -0.55 R^2 = 0.31	r = -0.51 R^2 = 0.26	r = -0.46 R^2 = 0.21	r = -0.47 R^2 = 0.22
1994-95	Hatching															
	Settlement	r = -0.01 R^2 = 0.0001	r = 0.42 R^2 = 0.17	r = 0.0004 R^2 = 0.00	r = 0.03 R^2 = 0.001	r = -0.53 R^2 = 0.28	r = -0.56 R^2 = 0.31	r = 0.04 R^2 = 0.002								

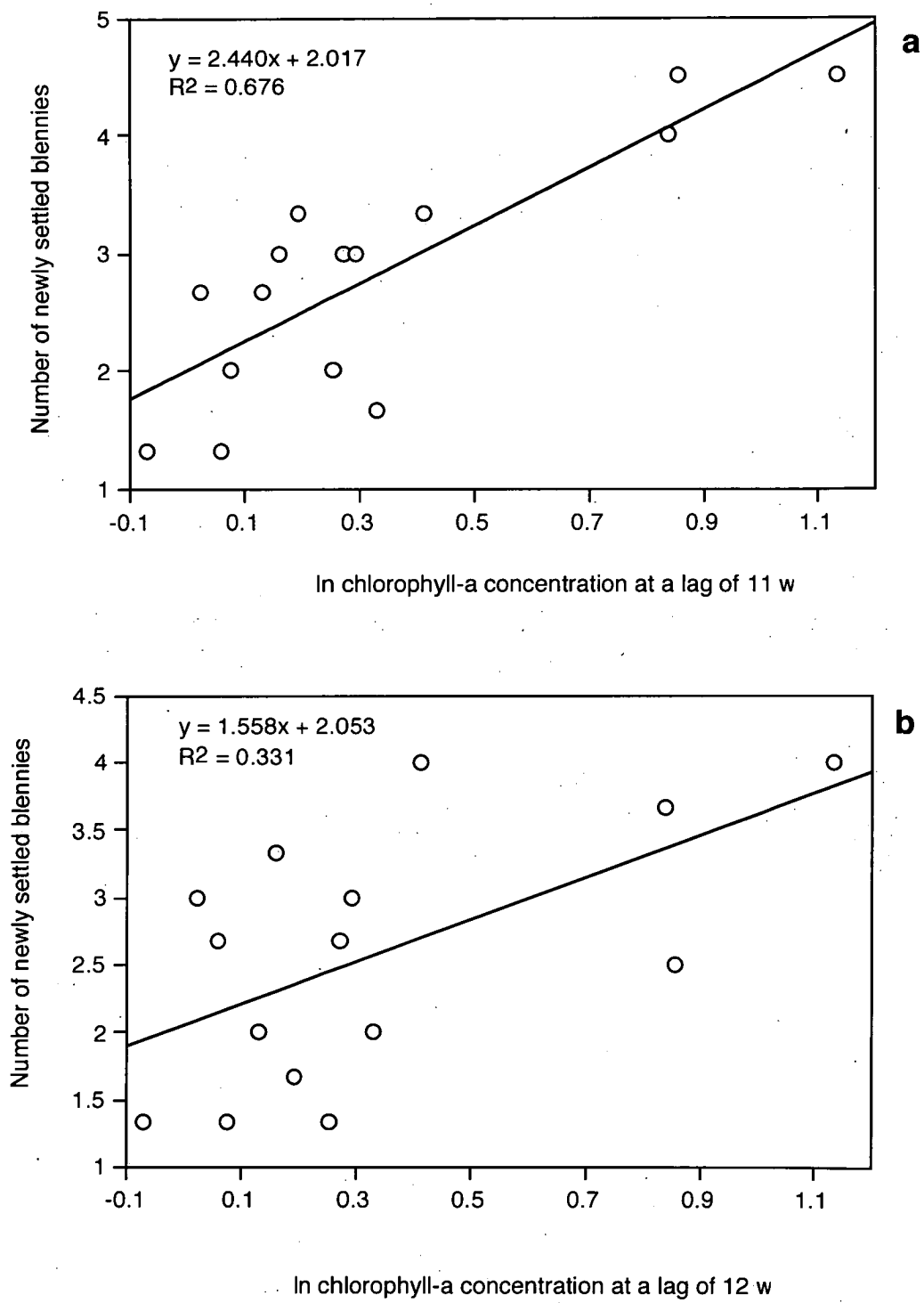

Figure 3.12. Regressions of ln chlorophyll-a concentration at a lag of 11 w (a) and 12 w (b) against settlement in 1992-93.

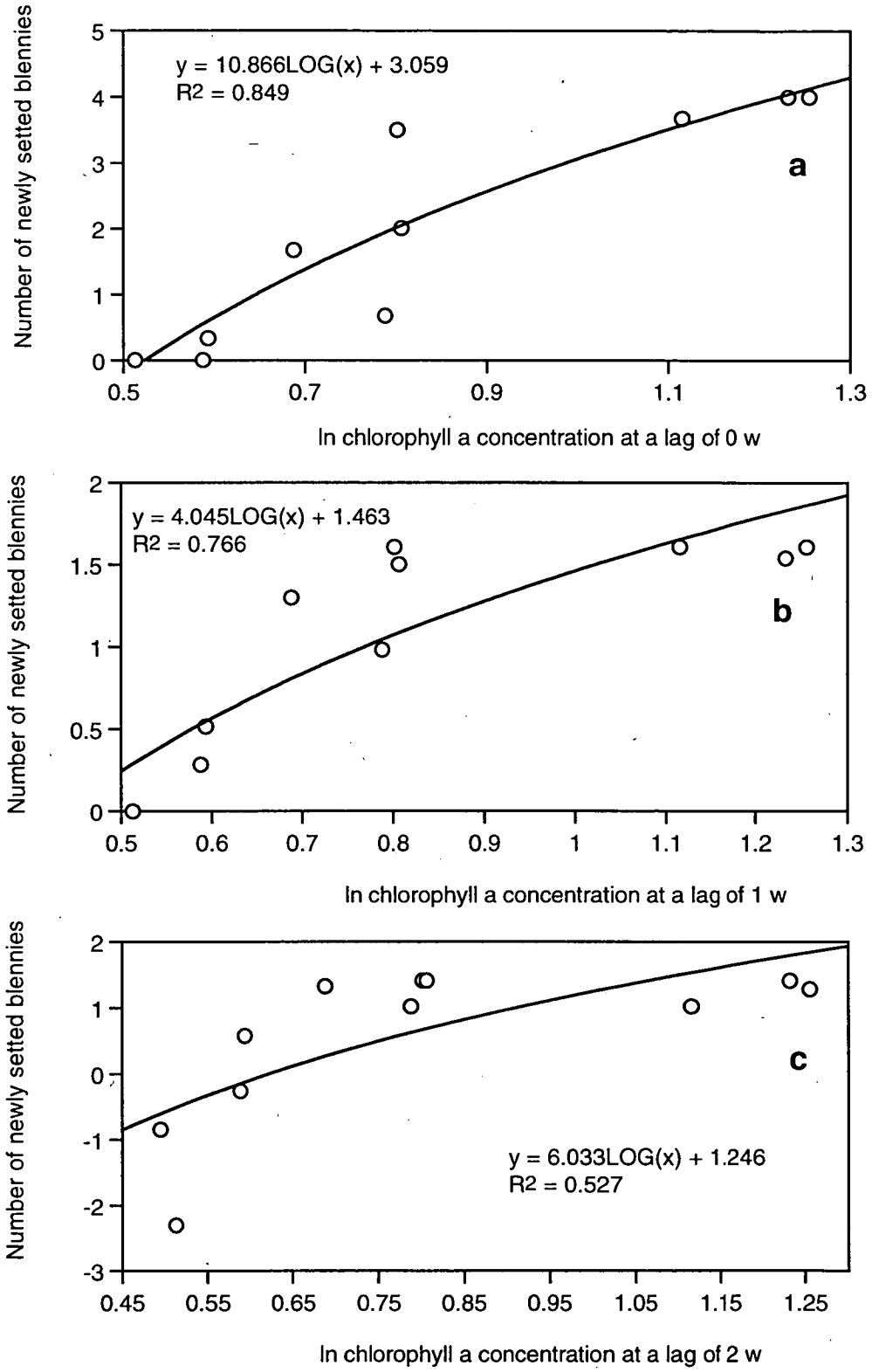

Figure 3.13. Regressions of ln chlorophyll a concentration at a lag of 0 w (a), 1 w (b), and 2 w (c) against number of newly settled blennies in 1993-94.

Table 3.10 R^2 and r value (correlation) of the relationship between larvae at week lag and back-calculated hatching date and back-calculated settlement date when weeks were averaged over years. Number in the first row corresponded to week lag. (* P < .01, ** P < .001, *** P < .0001)

Larvae		0	1	2	3	4	5	6	7	8	9	10
Surface	Hatching	r = -0.55*	r = -0.43	r = -0.73**	r = -0.83***	r = -0.85***						
		R^2 = 0.30	R^2 = 0.18	R^2 = 0.53	R^2 = 0.69	R^2 = 0.72						
	Settlement	r = 0.29	r = 0.40	r = 0.33	r = 0.15	r = -0.10	r = -0.39	r = -0.32	r = -0.44	r = -0.66**	r = -0.76***	r = -0.76***
		R^2 = 0.08	R^2 = 0.16	R^2 = 0.11	R^2 = 0.02	R^2 = 0.01	R^2 = 0.15	R^2 = 0.10	R^2 = 0.19	R^2 = 0.44	R^2 = 0.58	R^2 = 0.59
Subsurface	Hatching	r = -0.29	r = -0.11	r = -0.47	r = -0.54*	r = -0.54*						
		R^2 = 0.08	R^2 = 0.01	R^2 = 0.22	R^2 = 0.29	R^2 = 0.29						
	Settlement	r = 0.17	r = 0.40	r = 0.41	r = 0.41	r = 0.23	r = -0.01	r = 0.03	r = -0.10	r = -0.32	r = -0.41	r = -0.42
		R^2 = 0.03	R^2 = 0.16	R^2 = 0.17	R^2 = 0.16	R^2 = 0.05	R^2 = 0.0001	R^2 = 0.001	R^2 = 0.01	R^2 = 0.10	R^2 = 0.17	R^2 = 0.18

Table 3.11 R^2 and r value (correlation) of the relationship between larvae at week lag and back-calculated hatching date and back-calculated settlement date within years. Number in the first row corresponded to week lag. (* P < .01, ** P < .001, *** P < .0001)

Year	Larvae		0	1	2	3	4	5	6	7	8	9	10
1992-93	Surface	Hatching	r = 0.07 R^2 = 0.005	r = 0.70* R^2 = 0.50	r = 0.02 R^2 = 0.0003	r = -0.51 R^2 = 0.26	r = -0.46 R^2 = 0.21						
		Settlement	r = 0.10 R^2 = 0.01	r = 0.33 R^2 = 0.11	r = 0.46 R^2 = 0.23	r = 0.55 R^2 = 0.31	r = 0.56 R^2 = 0.31	r = 0.44 R^2 = 0.19	r = -0.001 R^2 = 0	r = -0.06 R^2 = 0.004	r = -0.18 R^2 = 0.03	r = -0.19 R^2 = 0.04	r = 0.07 R^2 = 0.005
	Subsurface	Hatching	r = -0.32 R^2 = 0.11	r = 0.57 R^2 = 0.33	r = -0.02 R^2 = 0.0003	r = -0.23 R^2 = 0.05	r = -0.14 R^2 = 0.02						
		Settlement	r = 0.37 R^2 = 0.14	r = 0.40 R^2 = 0.16	r = 0.34 R^2 = 0.12	r = 0.34 R^2 = 0.11	r = 0.16 R^2 = 0.02	r = -0.10 R^2 = 0.01	r = -0.31 R^2 = 0.10	r = -0.36 R^2 = 0.13	r = -0.22 R^2 = 0.05	r = 0.02 R^2 = 0.0003	r = 0.38 R^2 = 0.14
1993-94	Surface	Hatching	r = -0.07 R^2 = 0.005	r = -0.21 R^2 = 0.04	r = -0.31 R^2 = 0.10	r = -0.42 R^2 = 0.17	r = -0.43 R^2 = 0.18						
		Settlement	r = 0.19 R^2 = 0.04	r = 0.47 R^2 = 0.22	r = 0.63* R^2 = 0.40	r = 0.73* R^2 = 0.53	r = 0.40 R^2 = 0.16	r = 0.08 R^2 = 0.007	r = 0.06 R^2 = 0.004	r = 0.03 R^2 = 0.001	r = -0.12 R^2 = 0.01	r = -0.30 R^2 = 0.09	r = -0.39 R^2 = 0.15
	Subsurface	Hatching	r = 0.47 R^2 = 0.22	r = 0.27 R^2 = 0.07	r = 0.11 R^2 = 0.01	r = -0.07 R^2 = 0.004	r = -0.10 R^2 = 0.01						
		Settlement	r = -0.33 R^2 = 0.11	r = 0.12 R^2 = 0.01	r = 0.43 R^2 = 0.19	r = 0.74** R^2 = 0.55	r = 0.75* R^2 = 0.56	r = 0.66* R^2 = 0.44	r = 0.65* R^2 = 0.42	r = 0.55 R^2 = 0.30	r = 0.39 R^2 = 0.15	r = 0.16 R^2 = 0.02	r = -0.001 R^2 = 0

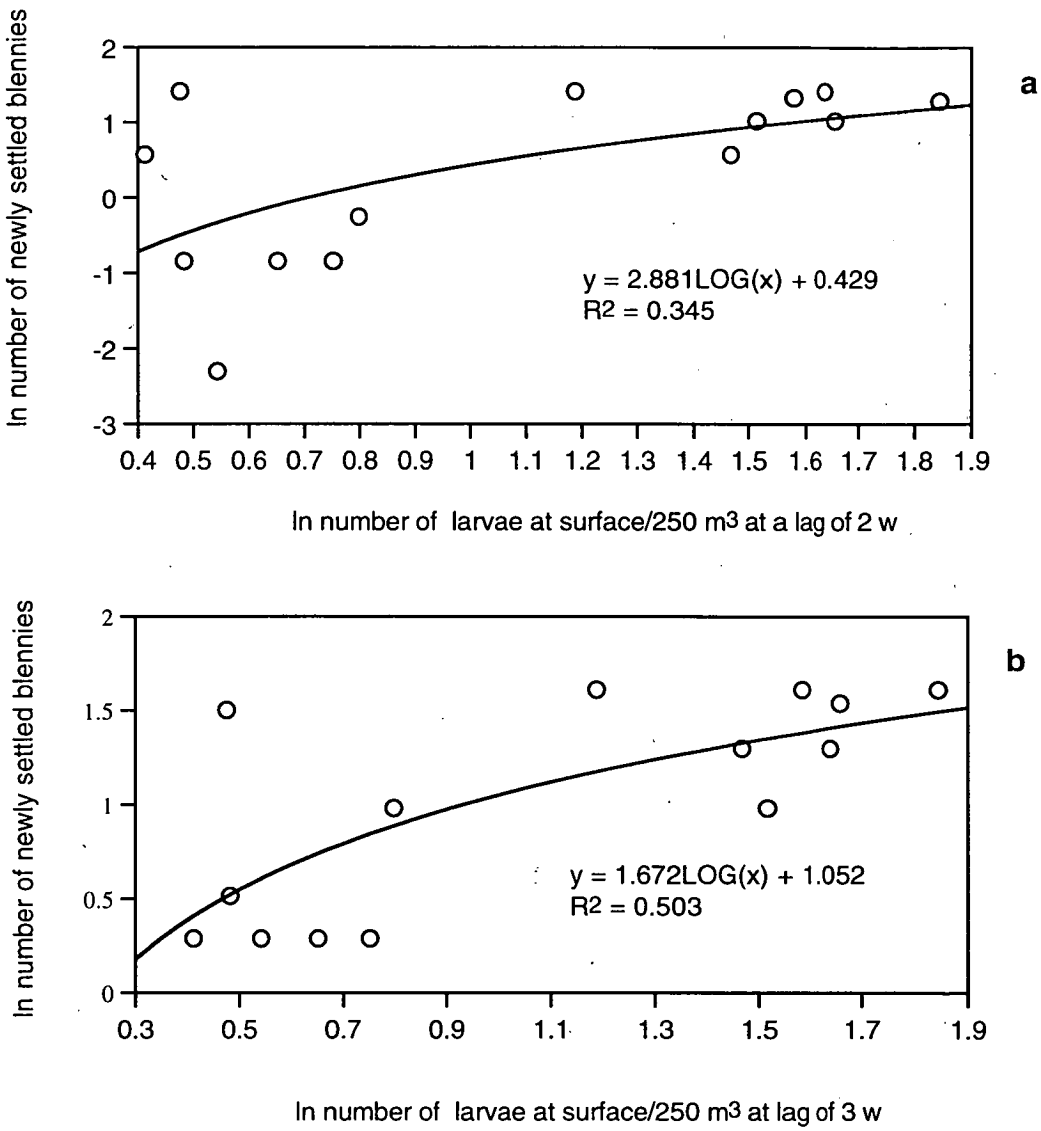

Figure 3.14. Regressions of ln number of larvae caught at surface at a lag of 2 w (a) and at a lag of 3 w (b) against ln number of newly settled blennies in 1993-94.

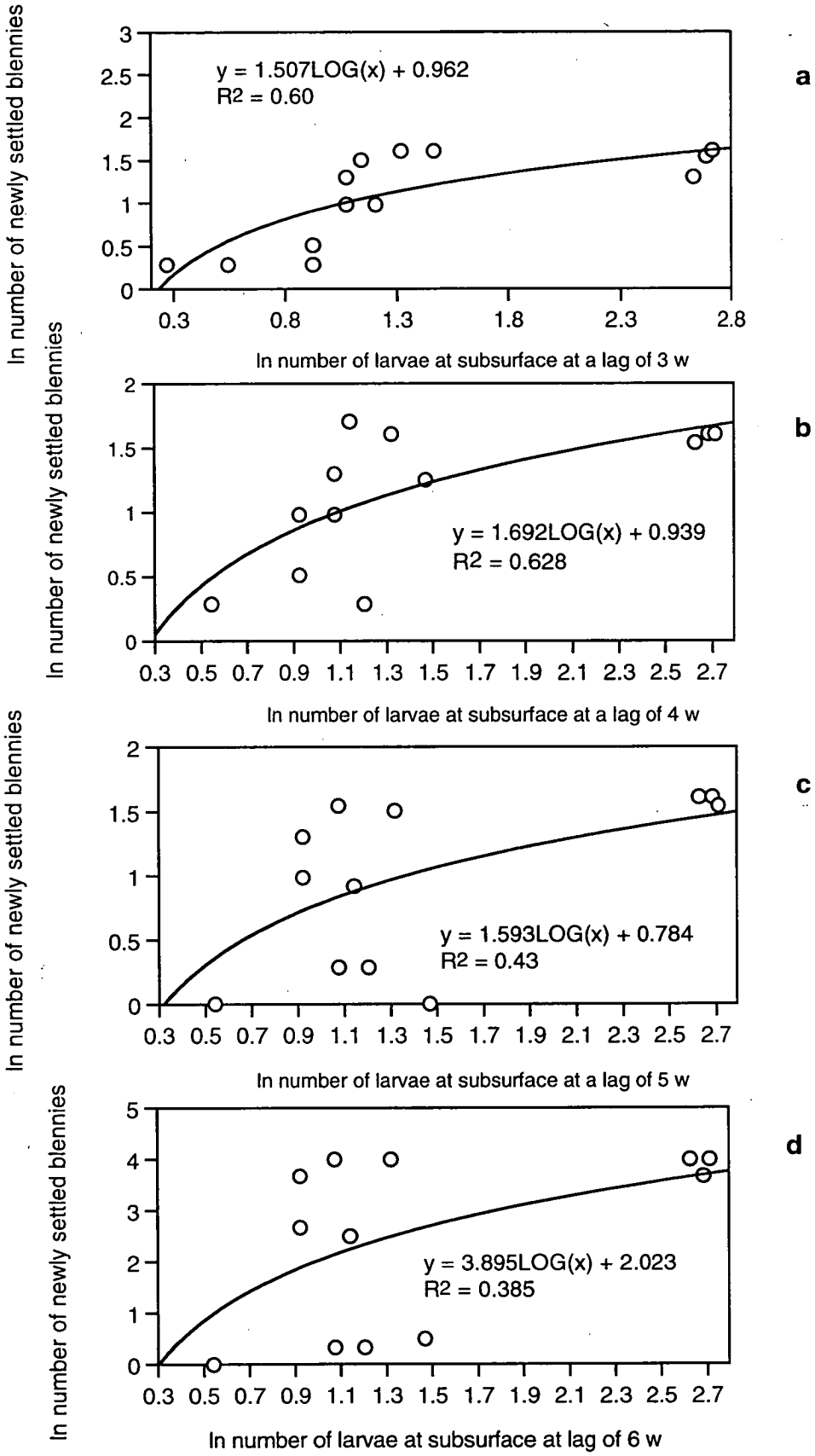

Figure 3.15. Regressions of ln number of larvae caught at subsurface/250 m3 at a lag of 3 w (a), 4 w (b), 5 w (c), and 6 w (d) against ln number of newly settled blennies in 1993-94.

There was no consistent correlation between number of larvae and the number of newly hatched blennies in 1993-94 (Table 3.11).

There were also negative correlations between the number of larvae, the number of back-calculated hatching blennies, and the number of back-calculated settled blennies at reasonable lag (up to 4 w for hatching and 10 w for settlement) when data were summed over years and for data within years (Table 3.10 and 3.11).

3.4 DISCUSSION

The Abundance of Larvae

The abundance of blenny larvae in 1992-93 was significantly lower than in 1993-94, most likely due to lower phytoplankton production (chlorophyll-a concentration) in 1992-93. Unfortunately, there were not enough data available to test (n = 2) this hypothesis. Cushing (1975) noted that the timing of both peak spawning activity of fish and the spring phytoplankton bloom could vary by several weeks from year to year but not necessarily in parallel. This suggests that fish reproductive strategies in an area should reflect the mean seasonal pattern of phytoplankton production, and that variation in the relative timing of spawning and seasonal plankton bloom could be a major determinant of interannual variability in survival. Fish in temperate waters should release their larvae during the spring or autumn peaks in the production cycle, when more food is available (Cushing, 1974, 1975; Cushing, 1990). This relates to the peak in spawning time of Tasmanian blennies which spawn frequently over a spring/summer breeding season that can last up to four months during peak periods of productivity (Cook, 1986). Seasonal cycles of production in the water-column in the Derwent River Estuary are typical of inshore temperate areas, with phytoplankton and zooplankton peaking in abundance during spring and autumn. The time and pattern of production differs from year to year, due in part to variations in the position of the main coastal currents (Newell, 1961; Harris et al., 1987). Consequently, difference in year class strength of blenny larvae was expected to be affected by the phytoplankton production in the Derwent River Estuary. However, primary production may be less important in spawning/hatching of blennies as they are estuarine species (Neira et al., 1992), therefore physical factors may have potential to disperse and affect spatial and temporal integrity.

However, difference in sampling strategies may have confounded the difference in blenny larval abundance. Although there are no strong data to test these hypotheses, the consistently low catches in 1992-93 imply larval sampling was not erratic. Heath (1992) suggested that larvae are generally extremely agile and proficient at evading nets or other towed devices. However, such competence may vary with a range of environmental parameters (Heath, 1992). Towing the net immediately behind the boat in this study may have increased avoidance. The different gears (1 m ring net and a pair of 50 cm bongo nets) and different towing methods (straight and spiral direction) used for larval sampling in the

present study have potential to cause the difference in abundance of larvae between years. However, comparison of larval sampling techniques suggested no difference in larval abundance between the two sampling strategies (chapter 2).

Low larval numbers in 1992-93 could reflect high rates of mortality due to unfavourable environmental conditions. Sequential weekly sampling of *P. t. tasmanianus* larvae provided no indication of modal increases in larval size, which could indicate high mortality of newly hatched larvae. Townsend (1983) found a similar pattern in the time-length-frequency distributions of *Pholis gunnellus* larvae, and drew a similar conclusion. Alternatively, reproductive effort by *P. t. tasmanianus* may have been lower in 1992-93, due to low fecundity, low adult biomass or both, although there was no data directly generated by the current study to support this hypothesis. However, research by Cook (1986) indicates that there is potential for interannual variation of this nature in larval production by Tasmanian blennies. Cook (1986) calculated the fecundity of *P. t. tasmanianus* to be 25,000-30,000 eggs annually which is high relative to the size of the adult. He found that reproductive output was reduced on low food rations by both reduction in batch sizes and by fewer spawnings. Periods of low larval abundance of blennies in the present study may be due to periods of low fecundity resulting from low rations.

The predominance of preflexion larvae in this study, both in 1992-93 and in 1993-94, indicates the blenny spawned throughout the spring and summer in both years. This agrees with the findings of both Cook (1986) and West (1988). The data also indicate that the period of peak larval abundance was consistent between years, with peaks in mid December. This peak tended to coincide with moon phase, as do other minor peaks in larval abundance each season (see chapter 5).

The Effect of Pulses in Phytoplankton Production on the Abundance of Larvae, Hatching Dates and Settlement

When data were pooled across years, there was no consistent relationship between chlorophyll-a concentration and larval abundance. Within years, the abundance of preflexion larvae correlated with chlorophyll-a concentration at a range of lags (from 0 to 6 weeks) both positively and negatively. Similarly, there was no consistent relationship between chlorophyll-a concentration and either number of back-calculated hatching blennies or number of back-calculated settled blennies when data were

pooled across years. Likewise, within years, the number of back-calculated hatching blennies and the number of back-calculated settled blennies correlated with chlorophyll-a concentration at a range of lags (from 0 to 14 weeks) both positively and negatively. This strongly suggests that there is no direct and simple mechanism linking the two variables, and perhaps no relationship at all; i.e., the within year correlations are spurious.

Unfortunately, there were not enough older larvae in the samples to determine if larval survival correlates with chlorophyll-a concentrations. It is conceivable that the abundance of newly hatched larvae varies with some other variables, such as moon phase. If food availability does affect survival then settlement should correlate with chlorophyll-a at hatching times (Thresher et al, 1989), which should occur at a lag of 6 to 10 weeks (planktonic larval period is 7 weeks on average and ranges from 6 to 10 weeks). However, a correlation between chlorophyll-a and number of back-calculated settled blennies at a lag of 11 and 12 weeks was found in 1992-93 but this indicates that phytoplankton production pulses affects eggs during the incubation period (4 weeks on average). No such relationship between chlorophyll-a and number of back-calculated hatching blennies was found in this study to confirm that chlorophyll-a may affect eggs and then resulted in a peak in newly hatched larvae. In addition, chlorophyll-a concentration correlated with the number of preflexion larvae at a lag of 6 weeks in 1992-93. This indicates that phytoplankton production pulses may induce adults to lay eggs.

Blenny larvae spend 7 weeks on average in the plankton (mean = 46 days), varying seasonally from a mean of ~ 5 weeks to 9 weeks. The sum of chlorophyll lags and the duration of the fish's larval stage, therefore, ranges from ~ 9 - 13 weeks, and averages 10-11 weeks. This suggests there should be a correlation between chlorophyll level and settlement at a lag of 9 weeks. However, I found no such relationship, which implies that the predictive ability of phytoplankton production pulses is low.

The lack of a clear relationship in this study was in agreement with Bainbridge et al. (1974) who found no clear relationship between the seasonal abundances of either clupeid (*Clupea harengus* L.) or scombrid (*Scomber scombrus* L.) larvae and the seasonal pattern of phytoplankton biomass over a 20 year period in sea areas of the North East Atlantic. Similarly, Sinclair (1988) cited many examples in which fish spawning times and larval survival apparently showed no relationship to the annual

phytoplankton production cycle. Sinclair (1988) assumes the physical factors predominates over food chain processes in the control of population biology. O'Boyle et al. (1984) stated that larval food supply (measured as phytoplankton) did not regulate larval populations of cod (*Gadus morhua*), haddock (*Melanogramus aeglefinus*), pollock (*Pollachius virens*), silver hake (*Merluccius bilinearis*), American plaice (*Hippoglossoides platessoides*) and redfish (*Sebastes* spp.). They suggested that currents may have a larval retention mechanism and these play an important part in the maintenance of stocks. Maintenance of the spatial integrity of any marine population, including fish, is regarded as the most important factor, and spawning times are adapted to the physical dispersive characteristics of an area rather than the primary productive characteristics. In blennies there was no such relationship between seasonal phytoplankton production and the abundance of larvae and settlement; this suggest that some of physical factors might affect the seasonal variation in abundance of larvae and settlement (chapter 4 and 5).

Larval Supply and Interannual-Variability in Settlement

Larval supply is not a good predictor of recruitment in *P. t. tasmanianus*. In 1993-94, the number of larvae collected at the surface at a lag of 2 and 3 weeks correlated with subsequent settlement patterns whereas larvae collected by subsurface tows at a lag of 3 to 6 weeks correlated with the number of back-calculated newly settled blennies. Mean settling age for blenny is 7 weeks (range 5 to 10 weeks), and age of larvae in the samples ranged in day from 0-7 days for 1992-93 and ranged from 0-10 days for 1993-94. The correlation between larval abundance and settlement at a lag of 5 and 6 weeks for larvae in subsurface tows in 1993-94 is feasible as this is in the region of larval development periods. However, correlations at lags of 2 to 3 weeks were considered spurious as this was insufficient time for the larvae to settle. The relationship between larval supply and number of newly settled blennies is spurious.

Apparent differences in larval abundance/supply, however, does not easily explain differences in year-class strength at settlement. The abundance of larvae in 1993-94 appeared to be much higher than in 1992-93 (although this is difficult to compare directly as different sampling techniques were used), but very few blennies settled in 1993-94. The non-linearity in the larval/settlement plots (Fig. 3.14 and 3.15) implies a density-dependent mortality of the larvae. Growth rate (length at otolith age) of larvae

collected in 1993-94 was slightly more rapid than larvae in 1992-93 (see chapter 5) suggesting no density-dependent growth effect. Therefore density-dependent growth leading to mortality of larvae appeared to be not able to explain the difference in settlement between years. However, it indicated that low settlement in 1992-93 may be due to slow growth rate of larvae resulting in low survival. Larvae with slow growth rate would be exposed to predators for a longer time which could result in higher mortality (Ricker and Foerster, 1948; Shepherd and Cushing, 1980; Jenkins et al., 1991), although planktonic predators were not assessed in this study. Reduction of growth rate may result from decreased food availability (Jenkins et al., 1991). As the percentage of larvae caught with food in their stomach was relatively low (33.33%, Chamchang, unpublished) in 1992-93, possibly low food availability which indicated starvation may have resulted in mortality of larvae leading to low settlement.

The low food availability may have resulted in competition for food between blenny larvae in high density patches leading to low settlement in 1993-94 as suggested for *Thunnus maccoyii* by Jenkins et al. (1991). The percentage of fish with food in stomach of larvae caught in 1993-94 was also relatively low (36.32%, Chamchang, unpublished), suggesting that low food availability could result in density-dependent mortality of larvae. Competition for food is assumed to be the main mechanism contributing to density dependant mortality (Lasker, 1987; Economou, 1991).

Relative low post-settlement growth rate may imply density-dependent effects during larval period which could result in increased mortality of larvae. Post-settlement growth rate of blennies in 1993-94 was slightly faster than in 1992-93 and density of settlement was slightly lower in this year. This suggests there may have been density-dependent mortality of larvae in 1993-94.

Peterman et al. (1988) demonstrated that there was no correlation between the abundance of eggs, yolk-sac larvae or early larvae and the number of Age I recruits in the northern anchovy *Engraulis mordax*. Sissenwine et al. (1984) also showed that for many stocks there was no relationship between numbers of larvae and subsequent recruitment. This emphasizes the importance of the mortality rate of older larvae in determining recruitment strength. This implies that older larvae should be examined although these are not always well sampled (Heath, 1992; Cushing and Horwood, 1994). Unfortunately, the older larvae of *P. t.*

tasmanianus in this study were not available to test the relationship with settlement. A far greater correlation between larval abundance and settlement is generally obtained if larvae are sampled just before settlement to give an accurate measure of larval supply (Dufour and Galzin, 1993). Where close relationship between larval supply and recruitment has been detected, sampling has often been based on larvae which were large and immediately pre-settlement (Dufour, 1991; Milicich et al., 1992; Thorrold et al., 1994a, 1994b, 1994c).

Because larval duration is so variable, there is probably less direct coupling between the hatching and recruitment. The timing and magnitude of settlement for blennies is likely to be influenced by larval duration, while a longer larval duration should result in greater losses to planktonic processes (Bailey and Houde, 1989). The larval duration of blennies varied from 36 to 69 days (pooled for all 3 years with mean = 46.3 days, S.D. = 6) and differed between years ($P < 0.0001$) with mean = 44.5 days, S.D. = 5.7 for 1992-93, mean = 56 days, S.D. = 5.9 for 1993-94 and mean = 45.1 days, S.D. = 3.9 for 1994-95. This suggests that low settlements of blennies in 1993-94 may be due to prolonged larval duration and thus increased time of exposure to predation (Bailey and Houde, 1989). Predation is now thought to be a major factor influencing recruitment variability (Hunter, 1981).

In conclusion, there seem to be no relationship between nutrient levels, phytoplankton blooms and larval abundance, hatching, or settlement of blennies at any reasonable lags which is in contrast to hypothesis of Thresher et al. (1989). Other factors may have masking effect on larval abundance and settlement.

In summary the main findings of this study were:

- Phytoplankton production (chlorophyll-a concentration) appeared to have no effect on hatching, the abundance of larvae and settlement variability.
- Apparent differences in larval abundance/supply of blennies does not easily explain differences in year-class strength at settlement.
- The plankton larval duration of *P. t. tasmanianus*, as determined from otolith analyses, varies seasonally from 36 to 69 days (mean = 46 days).
- The size of newly settled *P. t. tasmanianus* ranged in length from 15.7 to 18.4 mm SL (mean = 17.3 mm), and did not vary seasonally.

CHAPTER 4

EFFECT OF PHYSICAL FACTORS ON THE HATCHING DATE AND SETTLEMENT VARIABILITY OF TASMANIAN BLENNY

4.1 INTRODUCTION

The factors influencing the recruitment of reef fishes are complex. Hydrodynamics may play an important role in the temporal and spatial pattern of larval settlement, both through active responses of larvae to water movement, and also from passive transport. Rheotaxis, or active response to currents, for example, is well known in fishes, and has been demonstrated experimentally in larvae, juveniles, and adults (e.g. Arnold and Weihs, 1978; Hasler and Scholz, 1983; Champalbert and Marchand, 1994).

The most widely documented influence on intra-seasonal patterns of recruitment is the lunar cycle (Doherty, 1991). Thresher (1984) has suggested that most demersal spawners exhibit a semi-lunar spawning cycle. While spawning is usually influenced by the lunar cycle, subsequent recruitment patterns are diverse, ranging from highly variable episodic pulses (reviewed in Doherty and Williams, 1988) to events synchronised with lunar or tidal cycles (e.g. McFarland et al., 1985; Robertson et al., 1988; Robertson, 1992). Where the larval duration is fixed, synchronous spawning will naturally result in synchronous recruitment (e.g. Kingsford, 1980; Ochi, 1985; Robertson et al., 1988). However, synchronous settlement does not always imply synchronous spawning; in species with more variable larval durations (Victor, 1986). Victor (1986) suggested that a preferred settlement time can result in larval release that is entrained to lunar cycles. However, lunar spawning cycles may be absent in species that have variable-age settlers or lack preferred settlement periods (Christy, 1978; Kingsford, 1980).

Where spawning is controlled by lunar phase, a single population should have the same lunar spawning pattern in the same season each year (Christy, 1978; Kingsford, 1980). Most benthic species of reef fish show low settlement during the days around full moon (reviewed in Doherty, 1991) which is assumed to be an adaptation to reduce predation on

settling reef fishes (Hobson et al., 1981). In some species, this response to the lunar cycle is augmented by olfactory cues which the larvae use to choose among sites during nocturnal settlement (Sweatman, 1988).

The physical environment affecting fish in the inshore subtidal region is highly regulated by the tidal cycle, which may affect hatching. Hatching of damselfishes *Pomacentrus flavicauda* appear to follow cycles that are correlated with tidal states with maximum hatching occurring on days when spring high tides fall near sunset (Doherty, 1983). Doherty (1983) suggested that hatching at this time facilitated transport of the larvae off the reef by the ebbing tides.

Given the importance of tidal cycle on inshore areas, tide can also be expected to influence settlement; Thorrold et al. (1994b) suggested that most settlement-stage juveniles of inshore species utilise flood tides to move onshore. Settlement may also depend upon transport events other than tidal cycles to return settlement-stage larvae to reefs. Larval supply of several taxa of shorefish in Exuma Sound, Bahamas, has been shown to correlate with longshore or cross-shelf currents induced by wind (Shenker et al., 1993; Thorrold et al., 1994a). These wind-induced currents appeared to generate episodic peaks in larval supply of several days. Thorrold et al. (1994b) reported significant relationships between wind and larval supply of summer-recruiting reef fishes to Lee Stocking Island, Bahamas.

Temperature appears to be an important factor controlling the location and intensity of spawning/hatching in several species (reviewed by Bruce, 1982) and is the environmental variable most frequently linked to the recruitment variability of temperate marine fish (Sissenwine, 1984). Temperature has also been suggested to affect not only the magnitude but also size and age at metamorphosis of newly settled larvae. For example, McCormick and Molony (1995) examined the influence of temperature on size and age at metamorphosis of newly settled tropical goatfish, *Upeneus tragula* (Mullidae), and reported that standard length and age of fish at metamorphosis within and among samples were negatively related to mean water temperature. They also found in an experiment that fishes in 30°C water settled on average 2.8 days earlier than those held at 25°C.

Salinity has also been implicated as critical in determining hatching dates, either alone or interacting with temperature. Bays and estuaries tend to show marked salinity variations in response to periods of heavy rainfall,

high river discharge, flood tide, or drought, with salinity commonly ranging between 5‰ and 40‰. These large variations in salinity often play a more important role for estuarine and nearshore larvae, juveniles, and adults than temperature variation (reviewed in Bruce, 1982). The interaction of temperature and salinity commonly results in maximum hatch rates of temperate species along combinations of high temperature/high salinity to low temperature/low salinity (Alderdice and Forrester, 1968).

The Derwent River, the site for the current study, is an estuarine environment with much variation in both salinity and temperature. It is a drowned river valley (Fig. 4.1) which is highly stratified with salt-wedge that partially mixes with one major freshwater input at the estuarine head (Davies and Kalish, 1994). The river reaches sea level at New Norfolk, and then flows along a widening channel through a narrow coastal plain to Old Beach. The discharge beyond Dowsing Point, where the channel deepens markedly, occupies only a small fraction of the total depth; the estuarine discharge is essentially floating over the top of oceanic water. A little further downstream, near the Tasman Bridge, this surface flow often separates from the west bank and continues out to sea along the east bank (Thomson and Godfrey, 1985). Salinity profiles show the Derwent Estuary to be strongly stratified for most of the year. The upper estuary is typified by a sharp halocline at the upper end of the salt wedge changing into a mixing zone with a characteristic salinity gradient that increased in volume downstream (Davies and Kalish, 1994). Thus river discharge, rainfall, and their location of the mixing zone are factors affecting the sampling sites (Fig. 4.1) and may influence the hatching times and settlement of blennies.

In the previous chapter, it was shown that pulses in phytoplankton production do not appear to be related to hatching dates and the settlement of blennies. In this chapter, an alternative hypothesis, that hatching and settlement are determined by physical factors, was examined by seeking correlations of hatching and settlement with river discharge, rainfall, wind, tidal range, lunar phase, surface water temperature, and salinity.

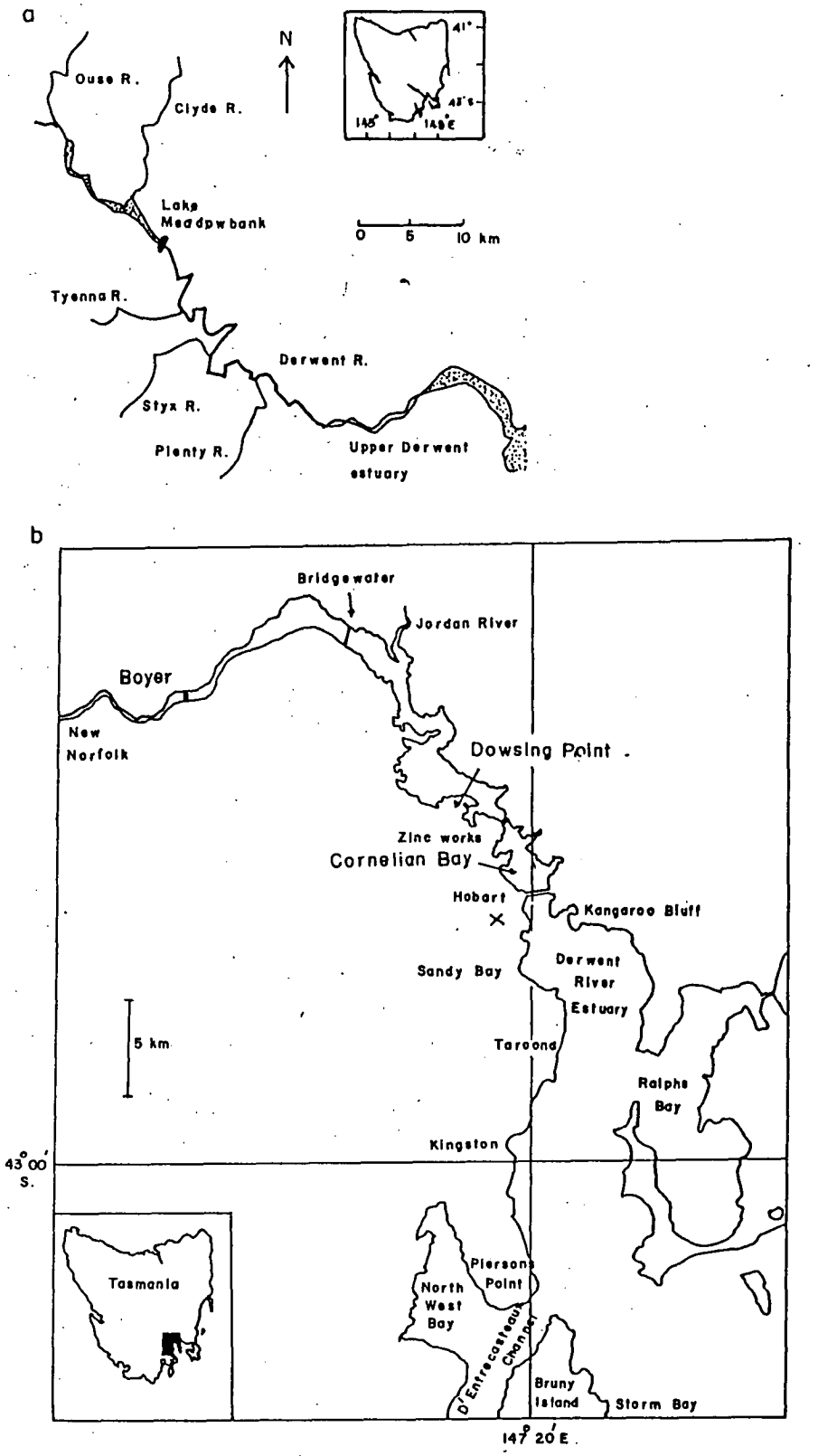

Figure 4.1. The Derwent River estuary showing the positions;
a. location for recording river discharge. The last 'run of the river' storage is indicated, along with major tributaries and the upper estuary (from Davies and Kalish, 1994).
b. The direction of the river flow (from Nyan Taw and Ritz, 1978).
"X"; location for wind data record.

4.2 MATERIALS AND METHODS

4.2.1 Sampling Site

Sampling was conducted at Taroona in the Derwent River Estuary, Storm Bay, as described in Chapter 2, Section 2.2 (Fig. 2.2).

4.2.2 Field Sampling

4.2.2.1 Sampling of Newly Settled Juveniles

Newly settled juveniles were collected bi-weekly during spring/summer in consecutive years between 1992 and 1995. Additional intensive settlement data were collected in 1996 (Section 4.2.3) for the purpose of determining temporal pattern within years. Protocol for the collection of fish is described in Chapter 2, Section 2.3.2.

4.2.2.2 Physical Factors Measurements

4.2.2.2.1 Tide

Daily tidal data were obtained for the Port of Hobart, as published by the Tidal Laboratory of the Flinders University of South Australia (1992, 1993, 1994, 1995 and 1996). For each day in the series, 'daily tidal range' was calculated as the difference between the highest tide and the lowest tide for that day.

4.2.2.2.2 Lunar Phase

Lunar periodicity data were obtained from astronomical data supplied by Australian Surveying and Land Information Group. For the purpose of analysis, the lunar cycle was split into 4 groups. These groups were formed using calendar days so that each lunar phase fell in the middle of the group.

4.2.2.2.3 Wind Pattern

Hourly wind data were recorded at Battery Point by the Bureau of Meteorology (Fig. 4.1). While these records are not a perfect measure of

conditions at the sampling sites, they broadly reflect the daily, weekly, seasonal, and interannual variability in the local weather. Due to the form of the estuary, south-easterly winds tend to cause the greatest wave action at Taroona, where samples were collected to analyse the effect of wind on settlement. The Taroona site was approximately 110° true north of Storm Bay. Consequently, the south-easterly component of the wind was calculated from wind velocity and wind direction by the formula:

$$SE = (S) \cos (\text{Degree to Radius } (\varnothing - 110^{o}))$$

where SE was the south-easterly component, S was the wind speed recorded in knots, and $\varnothing$ was the wind direction in degrees from true north. The equation transformed the entire wind field into north-westward and south-eastward blowing wind components. These components tended to have greatest influence on wave action. Wind speed data were collected as averages over eight hour periods, the maximum and mean daily value was then used in analysis of hatching and settlement variability of blennies.

4.2.2.2.4 Rainfall

Daily rainfall (mm) data were recorded at the Taroona sampling site by the Bureau of Meteorology, Hobart.

4.2.2.2.5 River Discharge

Mean daily Derwent River discharge (m^3/s) was recorded at Meadow Bank (Fig. 4.1) by the Tasmanian Hydro-Electric Commission for the periods 1992-93, 1993-94, 1994-95 and 1995-96 during spring/summer.

4.2.3 Intensive Settlement Dynamics

In 1992-93 and 1993-94, peaks of larval abundance corresponded to periods of high temperature and low salinity (Chapter 5). Consequently, it was hypothesised that the greatest settlement would occur in areas with high temperature and low salinity. To test this hypothesis, fortnightly sampling of settlement was undertaken in 1996 between 1st January and 6th March at three sites with different salinity and temperature characteristics.

4.2.3.1 Sampling Sites for Intensive Sampling

Sites with different temperature and salinity characteristics were chosen for sampling at Taroona, Sandy Bay Point, and Kangaroo Bluff in Storm Bay (Fig. 4.2). Taroona, the main sampling site, is an area of high salinity while Kangaroo Bluff, the site furthest upriver, has relatively low salinity. Sandy Bay, located between Kangaroo Bluff and Taroona, has intermediate salinity (Fig. 4.2).

4.2.3.2 Temperature and Salinity Measurements

The temperature and salinity of water at Kangaroo Bluff and Sandy Bay Point was measured just below the surface, adjacent to the tide pools, every second day during low tide. At Taroona, these measurement were collected from the water supply for the Taroona Marine Laboratories, Department of Primary Industry and Fisheries, which is pumped from a depth of 5 m.

Salinity of 100 ml water samples was measured using a WTW™ microprocessor conductivity meter (LF 196), which was calibrated using substandard seawater (a secondary standard seawater) previously determined to be 35‰. The salinity of the substandard seawater was measured against IAPSO standard seawater on a Yeokal™ 601 MkIV inductively coupled salinometer. All salinity measurements were conducted under constant temperature.

4.2.3.3 Sampling of Newly Settled Blennies

The settlement of blennies was investigated by sampling newly settled juveniles in three tide pools in the rock reef platform at each site. Method of collection was the same as that described in Chapter 2, Section 2.3.2.

4.2.4 Laboratory Analysis

4.2.4.1 Otolith Analysis

Hatching dates and settlement dates were back-calculated by otolith analysis as described in Chapter 2, Section 2.4.3.

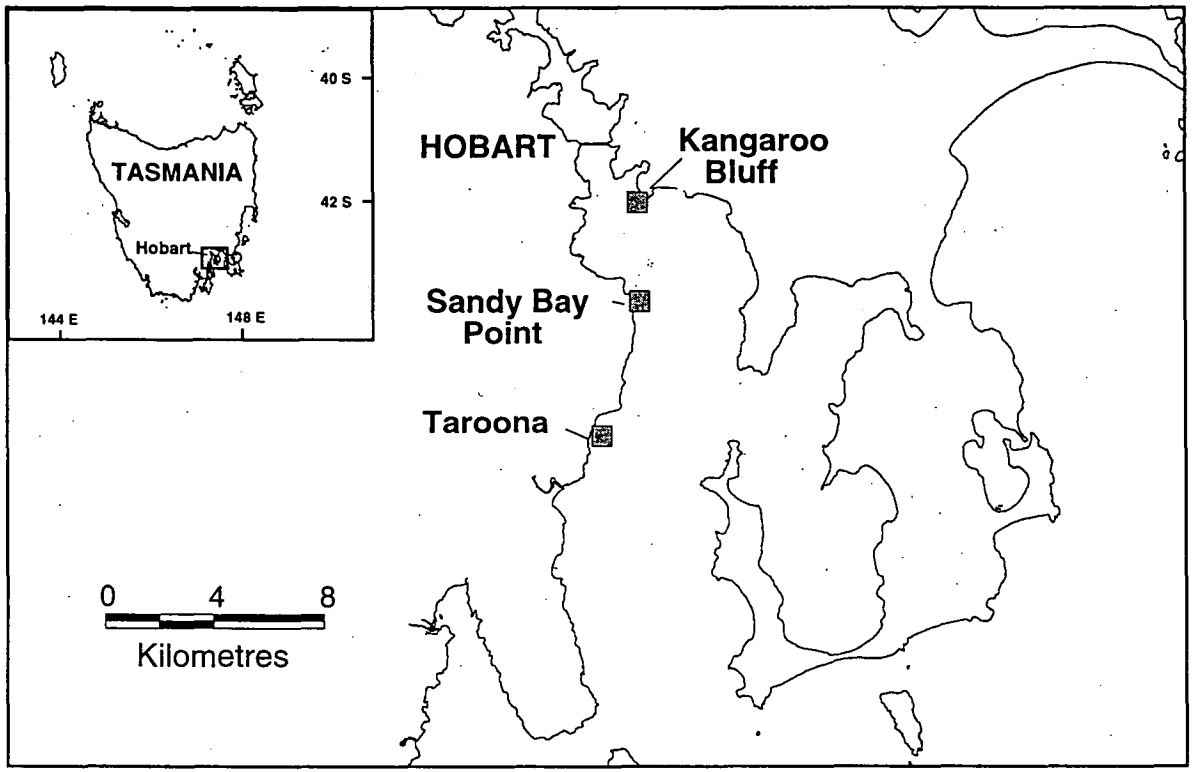

Figure 4.2 Sampling sites for intensive settlement dynamics study (Summer 1996). Solid rectangles indicate sites.

4.2.5 Statistical Analysis

The relationship between environmental factors and hatching and settlement was assessed at lags up to 7 d lag for hatching dates and settlement dates. Weekly mean data were also examined for long term effects at lags of up to 4 weeks (w) for hatching and 13 w for settlement (see Chapter 2, Section 2.5).

Data were analysed in several forms: pooled for all years, by separate years; and by day or by week. Stepwise, multiple regression (using the statistical package JMP 3.1) was used to find possible effects. However due to the large number of analyses undertaken, results were accepted with caution as numerous spurious relationships were indicated (Sokal, 1981). Consequently, relationships were only accepted as legitimate where the pattern was consistent over several years. The relationship between environmental factors that appeared to minimise error in the model was then assessed by classical linear regression (Myers, 1990). Prior to analysis, response variables were ln $(x + 1)$ transformed to produce normality and to remove heterogeneity of variance (Myers, 1990). In additional analyses, sampling noise was reduced by calculating moving averages over 3 adjacent points.

To control effects which may have obscured relationships between physical factors and number of newly hatched blennies and newly settled blennies, data were manipulated by 3 ways. The basis for these manipulations was that periods with low larval supply would inevitably result in periods of low settlement; the best indication of effects of environmental conditions is likely to be deviation a simple pattern of high larval supply resulting in high settlement. First, all data points collected before or after the main hatching and settlement period were excluded. Secondly, data from 1991-92 and 1992-93 were excluded as very low hatching and settlement recorded in these years; it was considered that error introduced by this small sample size may have obscured relationships with physical factors. Thirdly, a correction was made for the observed significantly lower hatching periods. Settlement data were excluded from the analyses on the week falling 46 days after low hatching, as mean larval durations is approximately 46 days (see Chapter 3, Section 3.3.6). Periods of low hatch were identified from larval samples collected by plankton tows. Where no data from plankton tows were available, periods of expected low larval supply based on observed patterns around lunar phases, were excluded.

For weekly analyses, rainfall and river discharge data were the sum of rainfall precipitation and sum of river discharge within each week. The value used for the weekly maximum wind was the highest maximum daily wind for each week. Mean weekly wind was the average of daily wind within a week.

In analysis of other physical factors, correlations were assessed for lags of up to 13 weeks (see chapter 2), however, for river discharge, correlations were only assessed for 10 weeks lag due to lack of river flow data for the remaining 3 weeks.

4.3 RESULTS

4.3.1 Temporal Pattern of Hatching and Settlement

Hatching dates were back-calculated from settlement data and frequency is shown in Figs. 4.3a (pooled by calendar week) and 4.5a (daily back-calculated hatching dates). Relatively low level of hatching was recorded in 1992-93 and 1993-94 with significantly higher hatching in 1994-95 and 1995-96 ($P < 0.001$). As hatching was back-calculated from settlement, this observed difference in hatching rate reflects overall difference between years in settlement. Each year, blennies apparently began to hatch in October or early November and continued into January, with peak hatching in 1994-95 and 1995-96 occurring in November. The intensity of hatching usually decreased by early January.

The distribution of back-calculated weekly and daily settlement dates are shown in Figs. 4.3b and 4.5b respectively. In 1994-95 and 1995-96, settlement was clustered around late January. Few blennies settled in 1992-93 and 1993-94, but the seasonal pattern was generally similar to that of 1994-95 and 1995-96 (Fig. 4.3b). Total number of settled juveniles collected was highest in 1995-96 ($n = 148$) followed by 1994-95 ($n = 127$), 1992-93 ($n = 51$), and 1993-94 ($n = 30$) (effect of year on settlement was significant at $P < 0.05$). Settlement appeared to begin each year in January and continued at least into March. Sampling in 1992-93 indicated that some low level settlement continued after March; these back-calculated, newly settled juveniles were samples collected in May to examine later-settling, slow-growing juveniles. In some years, settlement of blennies occurred in small numbers in December, but major settlement never occurred before January.

4.3.2 Effect of Tides on Hatching Dates and Settlement Variability

The pattern of weekly tidal range in relation to hatching and settlement of blennies are shown in Fig. 4.4a and 4.4b. Daily patterns were less clear and are shown in Appendix 2 and 3.

Hatching

Correlations between daily hatching dates and tidal range at any reasonable lag of days are shown in Table 4.1; these correlations are for

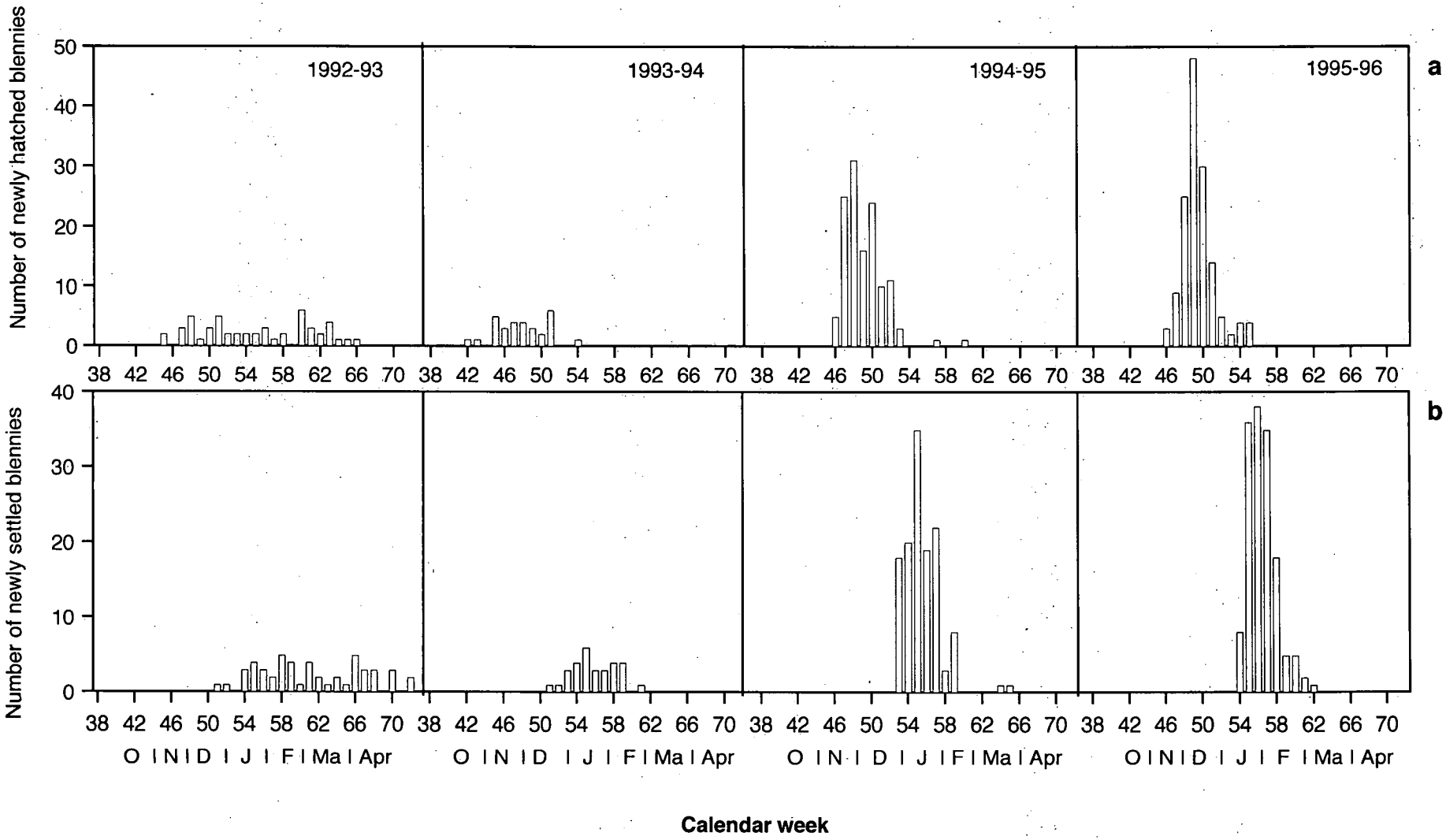

Figure 4.3. Weekly patterns of back-calculated hatching (a) and settlement (b) of blennies during spring/summer 1992-93 to 1995-96.

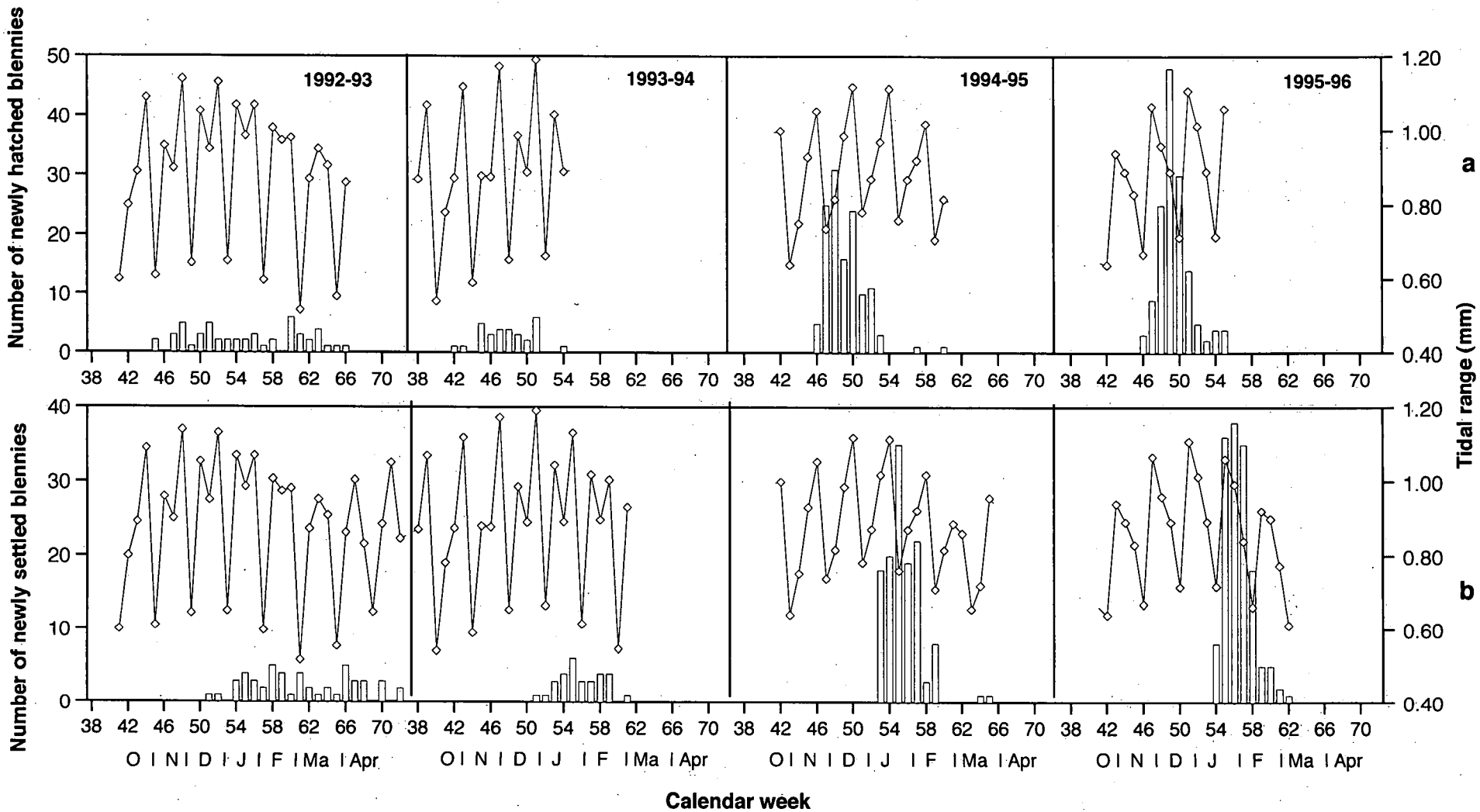

Figure 4.4. Mean weekly tidal range and number of newly hatched blennies (a) and number of newly settled blennies (b) during spring/summer from 1992-93 to1995-96. Bar charts show number of blennies pooled by calendar week; line charts show mean tidal range.

Table 4.1 Correlations (r) between back-calculated hatching dates and tidal range at a reasonable lag of days. Data points collected before or after the main peak in hatching were excluded. *, **: Correlation significant at $P < 0.05$, $P < 0.01$, respectively.

Physical factor	Day lag	4 Years pooled n = 228	1992-93 n = 100	1993-94 n = 49	2 Years (1994-95&1995-96) pooled; n = 79	1994-95 n = 46	1995-96 n = 33
Tidal range	0	- 0.05	0.06	0.15	- 0.25*	- 0.18	- 0.44**
	1	- 0.05	0.07	0.09	- 0.21	- 0.11	- 0.43**
	2	- 0.04	0.06	0.04	- 0.15	- 0.03	- 0.38*
	3	- 0.02	0.05	- 0.03	- 0.07	0.05	- 0.29
	4	0.001	0.08	- 0.07	0.002	0.11	- 0.18
	5	0.02	0.08	- 0.06	0.07	0.16	- 0.05
	6	0.03	0.06	- 0.05	0.11	0.15	0.10
	7	0.03	0.03	- 0.05	0.14	0.12	0.23

data with points before or after main peak in hatching excluded. When data were pooled for all 4 years, no significant relationship was found but when only data in 1994-95 and 1995-96 were pooled, an inverse significant correlation appeared at a lag of 0 d. This relationship appeared to be largely attributable to settlement patterns in 1995-96 as significant correlations were only present in this year at a lag of 0, 1 and 2 d.

Correlations between weekly hatching and tidal range at any reasonable lag of weeks are shown in Table 4.2. When data were pooled across 4 years and across 2 years, no correlation occurred. Within years, an apparently significant negative correlation emerged only in 1993-94 at a lag of 3 w.

In summary, no consistent effect of tidal range on back-calculated hatching was found by regression analysis at any reasonable lag of days or weeks ($P > 0.05$).

Settlement

Tidal range appeared to have no consistent effect on settlement of blennies at any reasonable lag of days and lag of weeks when data were pooled across all 4 years or pooled for the 2 years with high settlement ($P > 0.05$). There also appeared to be no consistent correlation for any individual year (Table 4.3 and Table 4.4 respectively; data points before or after main peak in settlement were excluded).

Settlement - Excluding periods of low hatching

Further analysis of correlations between newly settled blennies (daily data and weekly data) and tidal range, when data were screened to remove back-calculated periods where hatching was low or absent, are shown in Table 4.5 and Table 4.6. No consistent relationship emerged when data were pooled for all 4 years or pooled for the 2 years with high settlement (1994-95 and 1995-96). Within years, an apparently significant negative correlation between newly settled blennies and tidal range emerged in 1992-93 at lag of 5 d (Table 4.5). There was also an apparently significant positive correlation at a lag of 12 w in 1993-94 ($P < 0.05$, Table 4.6).

In summary, there were no consistent correlations between tidal range and back-calculated hatching dates or settlement over varying lags when analysed over both daily and weekly periods.

Table 4.2 Correlations (r) between back-calculated hatching dates and tidal range at reasonable lag of weeks. Data points collected before or after the main peak in hatching were excluded. * : Correlation significant at $P < 0.05$.

Physical factor	Week lag	4 Years pooled n = 42	1992-93 n = 17	1993-94 n = 7	2 Years (1994-95&1995-96) pooled; n = 18	1994-95 n = 8	1995-96 n = 10
Tidal range	0	0.06	0.27	0.34	- 0.05	- 0.29	0.07
	1	- 0.03	- 0.11	- 0.18	0.06	- 0.03	0.09
	2	0.08	0.07	0.54	0.08	0.37	- 0.09
	3	- 0.27	- 0.41	- 0.76*	- 0.22	- 0.21	- 0.20
	4	- 0.06	0.27	0.27	- 0.23	- 0.65	- 0.08

Table 4.3 Correlations (r) between daily settlement and tidal range at reasonable lag of days. Data points collected before or after the main peak in settlement were excluded. No correlations were significant ($P > 0.05$).

Physical factors	Day lag	4 Years pooled n = 244	1992-93 n = 103	1993-94 n = 45	2 Years (1994-95&1995-96) pooled; n = 96	1994-95 n = 47	1995-96 n = 49
Tidal range	0	- 0.01	- 0.01	- 0.01	- 0.002	- 0.123	0.14
	1	- 0.02	- 0.07	0.07	- 0.005	- 0.13	0.15
	2	- 0.03	- 0.103	0.17	- 0.02	- 0.12	0.09
	3	- 0.001	- 0.15	0.24	0.04	- 0.03	0.14
	4	0.05	- 0.07	0.25	0.103	0.09	0.13
	5	0.07	- 0.12	0.20	0.15	0.21	0.11
	6	0.09	- 0.05	0.10	0.16	0.29	0.05
	7	0.14	0.02	- 0.01	0.22	0.33	0.15

Table 4.4 Correlations (r) between weekly settlement and tidal range at a reasonable lag of weeks. Low settlement periods before or after main peak in settlement were excluded. No correlations were significant (P > 0.05).

Physical factor	Week lag	4 Years pooled n = 38	1992-93 n = 17	1993-94 n = 7	2 Years (1994-95&1995-96) pooled; n = 14	1994-95 n = 7	1995-96 n = 7
Tidal range	0	0.15	0.35	0.47	0.09	- 0.15	0.29
	1	0.12	- 0.15	0.25	0.25	0.10	0.38
	2	0.01	- 0.08	- 0.19	0.19	0.10	0.26
	3	0.16	0.28	- 0.37	0.07	0.45	- 0.28
	4	0.17	0.40	0.56	- 0.08	- 0.33	0.11
	5	0.05	- 0.27	0.17	0.004	- 0.21	0.17
	6	- 0.02	- 0.04	- 0.29	0.12	0.005	0.22
	7	0.05	0.18	- 0.34	- 0.05	0.32	- 0.40
	8	0.07	0.40	0.64	- 0.21	- 0.48	- 0.03
	9	- 0.09	- 0.34	0.19	- 0.12	- 0.32	0.03
	10	- 0.18	- 0.04	- 0.42	0.04	- 0.05	0.13
	11	- 0.14	0.02	- 0.36	- 0.11	0.22	- 0.46
	12	- 0.10	0.31	0.72	- 0.32	- 0.51	- 0.17
	13	- 0.21	- 0.45	0.25	- 0.27	- 0.31	- 0.24

Table 4.5 Correlations (r) between settlement and tidal range at reasonable lag of days. Settlement periods where hatching was low were excluded. *: Correlation significant at $P < 0.05$.

Physical factors	Day lag	4 Years pooled n = 143	1992-93 n = 42	1993-94 n = 22	2 Years (1994-95&1995-96) pooled; n = 79	1994-95 n = 41	1995-96 n = 38
Tidal range	0	0.12	0.01	0.04	0.09	- 0.03	0.29
	1	0.11	- 0.03	0.04	0.04	- 0.02	0.14
	2	0.08	- 0.16	0.03	- 0.01	- 0.001	- 0.01
	3	0.10	- 0.22	0.02	0.03	0.08	- 0.04
	4	0.11	- 0.23	- 0.02	0.05	0.18	- 0.12
	5	0.11	- 0.31*	- 0.07	0.09	0.25	- 0.13
	6	0.14	- 0.15	- 0.09	0.08	0.28	- 0.15
	7	0.19	- 0.08	- 0.08	0.17	0.28	0.06

Table 4.6 Correlations (r) between settlement and tidal range at reasonable lag of weeks. Settlement periods where hatching was low were excluded. No correlations were significant ($P > 0.05$).

Physical factor	Week lag	4 Years pooled n = 33	1992-93 n = 14	1993-94 n = 6	2 Years (1994-95&1995-96) pooled; n = 13	1994-95 n = 7	1995-96 n = 6
Tidal range	0	0.19	0.35	0.47	0.10	- 0.15	- 0.40
	1	0.15	- 0.04	0.25	0.29	0.10	0.54
	2	0.03	- 0.13	- 0.21	0.01	0.10	- 0.09
	3	0.08	0.35	- 0.39	- 0.01	0.45	- 0.56
	4	0.22	0.43	0.58	- 0.05	- 0.33	0.24
	5	0.07	- 0.15	0.17	0.11	- 0.21	0.49
	6	0.002	- 0.09	- 0.32	- 0.02	0.005	- 0.08
	7	- 0.03	0.23	- 0.34	- 0.09	0.32	- 0.60
	8	0.14	0.39	0.72	- 0.17	- 0.48	0.11
	9	- 0.08	- 0.26	0.19	0.02	- 0.32	0.46
	10	- 0.15	- 0.12	- 0.45	- 0.07	- 0.05	- 0.15
	11	- 0.24	0.03	- 0.36	- 0.09	0.22	- 0.55
	12	- 0.04	0.27	0.84*	- 0.27	- 0.51	- 0.02
	13	- 0.20	- 0.39	0.24	- 0.14	- 0.31	0.05

4.3.3 Effect of Lunar Phase on Hatching Dates and Settlement Variability

Hatching

The pattern of hatching dates in relation to lunar phases is shown in Fig. 4.5a. Back-calculated hatching dates did not exhibit any evident periodicity in relation to lunar phase when data were pooled for all 4 years ($P > 0.05$, Fig. 4.6).

Since hatching dates for settled juveniles in 1992-93 and 1993-94 were very low, these years were excluded in additional analyses so that the effect of moon phase in 1994-95 and 1995-96 could be determined separately. Hatching in 1994-95 and 1995-96 did not exhibit any evident periodicity in relation to lunar phase ($P > 0.05$, Fig. 4.6). However, there was a trend of high hatching occurring during the full moon period, largely attributable to patterns of hatching in 1995-96 (Figs. 4.6 and 4.7).

When analysed by separate year, there appeared to be significant periodicity of hatching in relation to lunar phase only in 1995-96 ($P < 0.001$) with highest hatching occurring during the full moon period (Fig. 4.7d).

Settlement

The pattern of settlement in relation to the lunar cycle is shown in Fig. 4.5b. To assess whether settlement exhibited periodicity in relation to lunar phase, data points before or after the main peak in settlement were removed. Data were also screened to remove periods where settlement could be expected to be low based on periods of low or no hatching (based on larval duration of approximately 46 days - mean larval period of blennies, see Chapter 3).

The frequency of settlement in relation to the lunar cycle, with data points before or after main peak removed, is shown in Figs. 4.8 and 4.9. When data were pooled for all 4 years and pooled for the 2 years with high settlement in 1994-95 and 1995-96, settlement did not have significant periodicity in relation to lunar phase ($P > 0.05$). However, there was a strong trend of high settlement during the waxing half moon and lower settlement during the full moon period (Fig. 4.8). Within years, settlement did not exhibit the evident periodicity in relation to moon phase for any year ($P > 0.05$, Fig. 4.9).

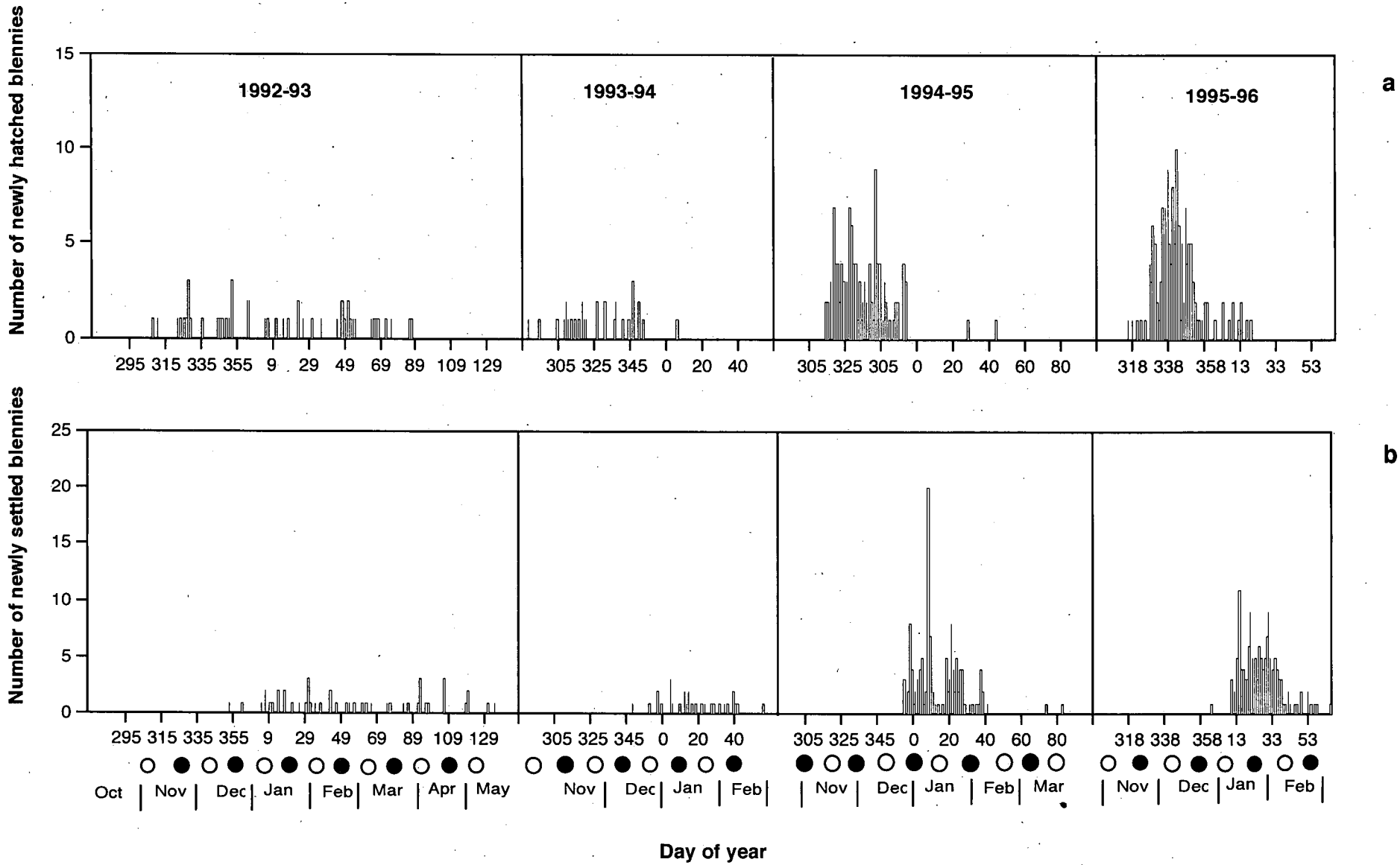

Figure 4.5. Relationship between lunar cycle and patterns of hatching (a) and settlement (b) during spring/summer from 1992-93 to 1995-96; open circle represent full moon and closed circle represent new moon.

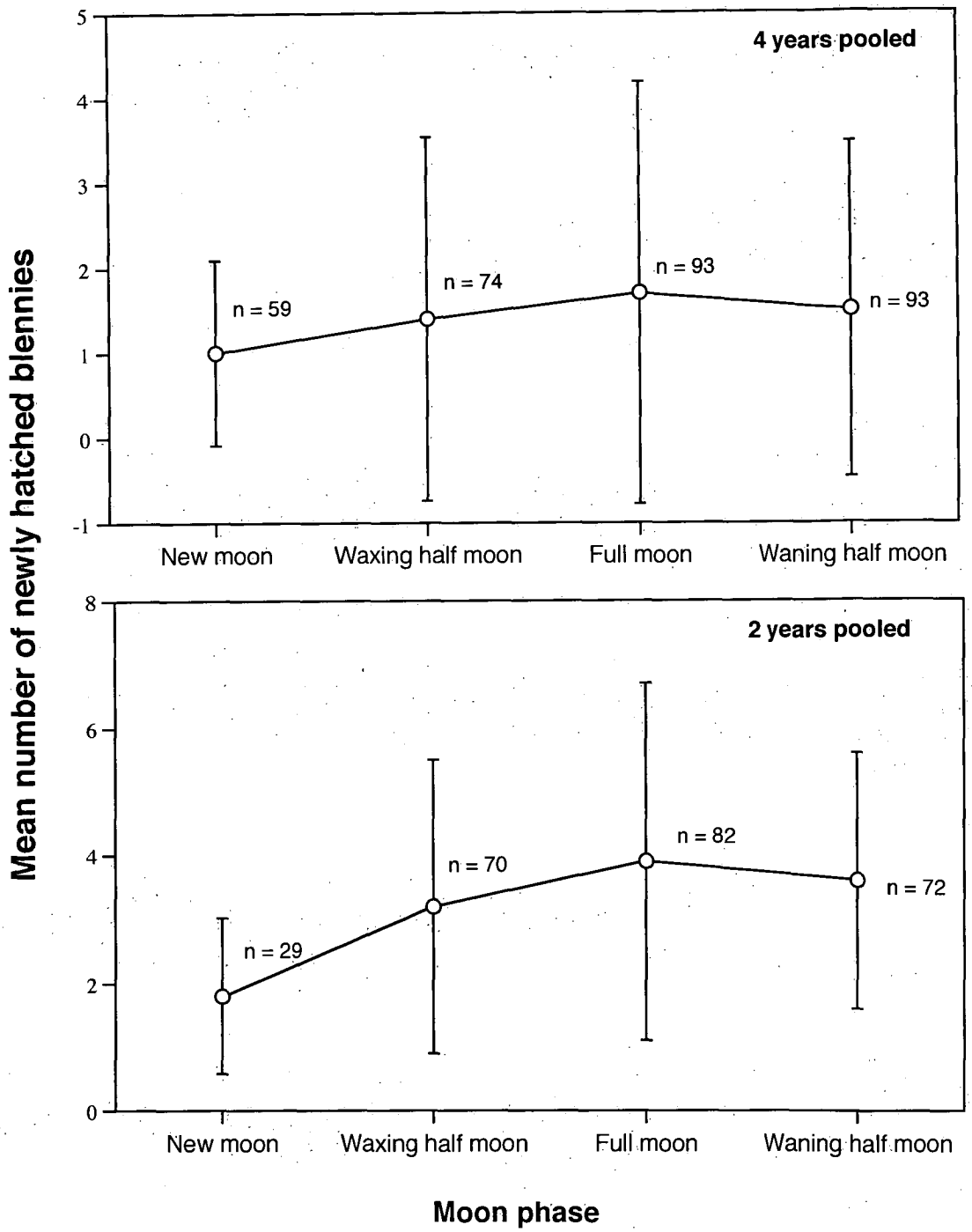

Figure 4.6. Mean number of newly hatched blennies in relation to lunar phase when data were pooled for all 4 years (top) and for 2 years (bottom); vertical lines = standard deviation.

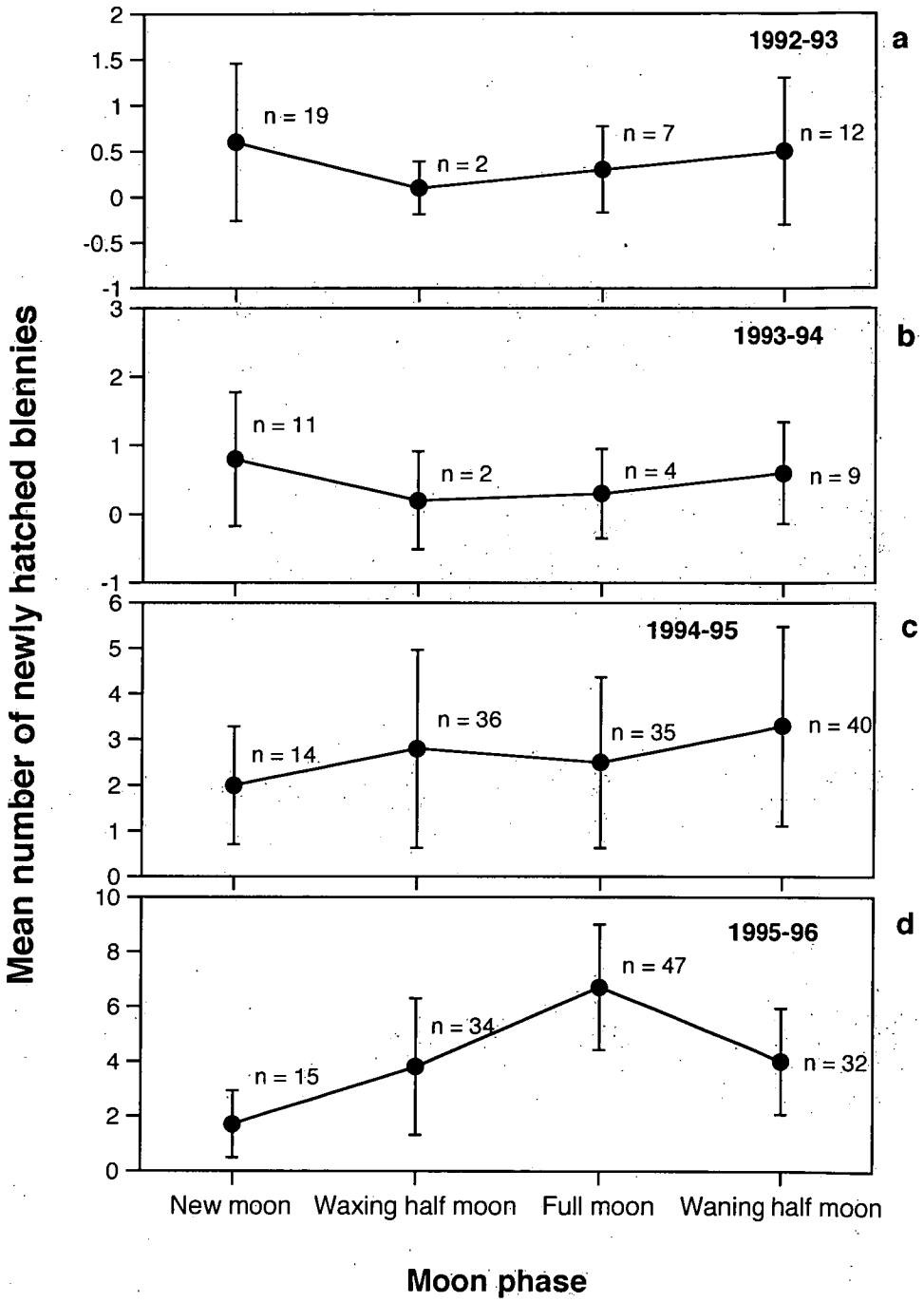

Figure 4.7. Mean number of newly hatched blennies in relation to lunar phases for seperate years 1992-93 to 1995-96 (a-d); vertical lines = standard deviation.

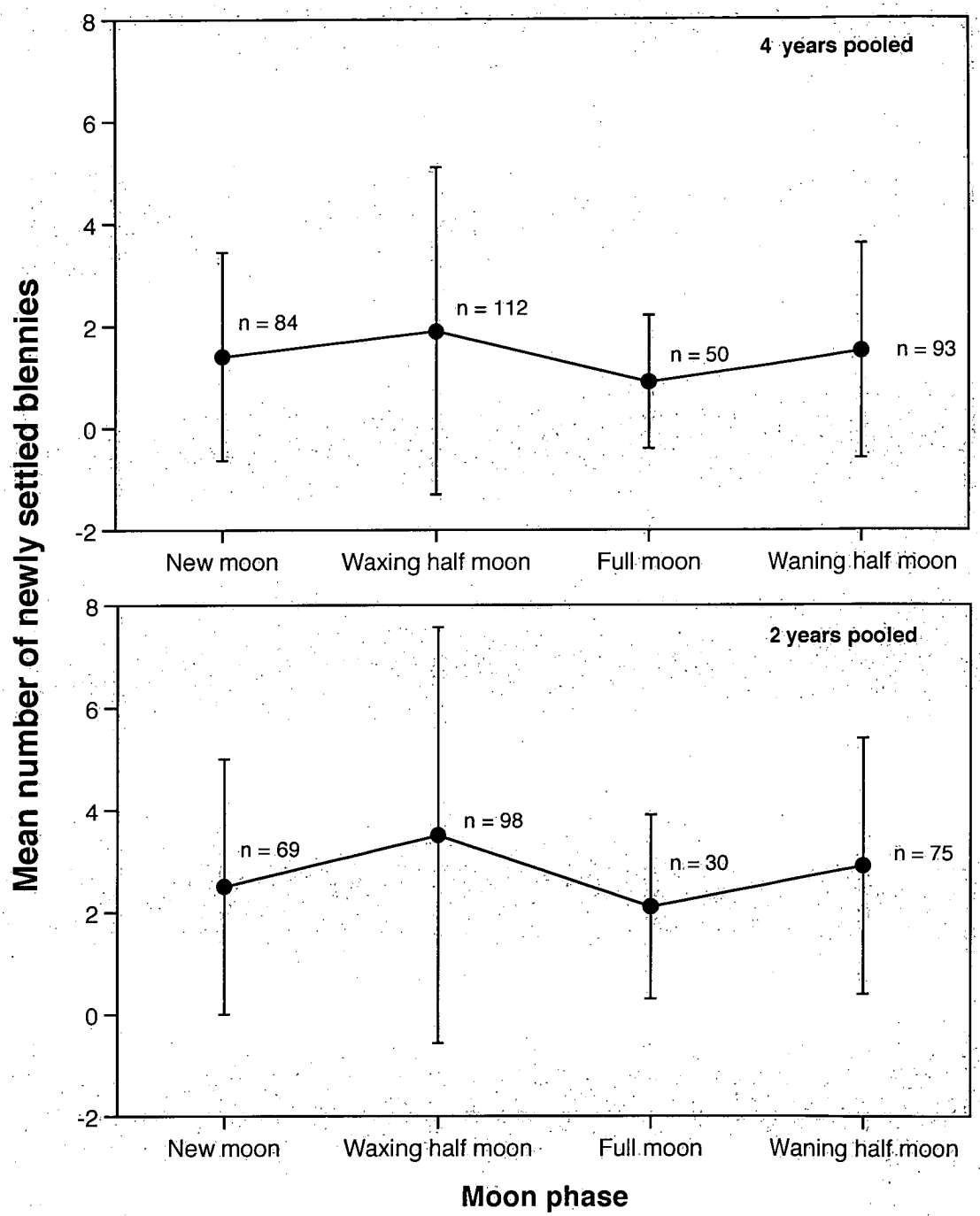

Figure 4.8. Mean number of newly settled blennies occurring during each lunar phase when data were pooled for all 4 years (top) and for 2 years in 1994-95 and 1995-96 (bottom). Plots are based on data with information collected before of after the main peaks of settlement excluded; vertical lines = standard deviation.

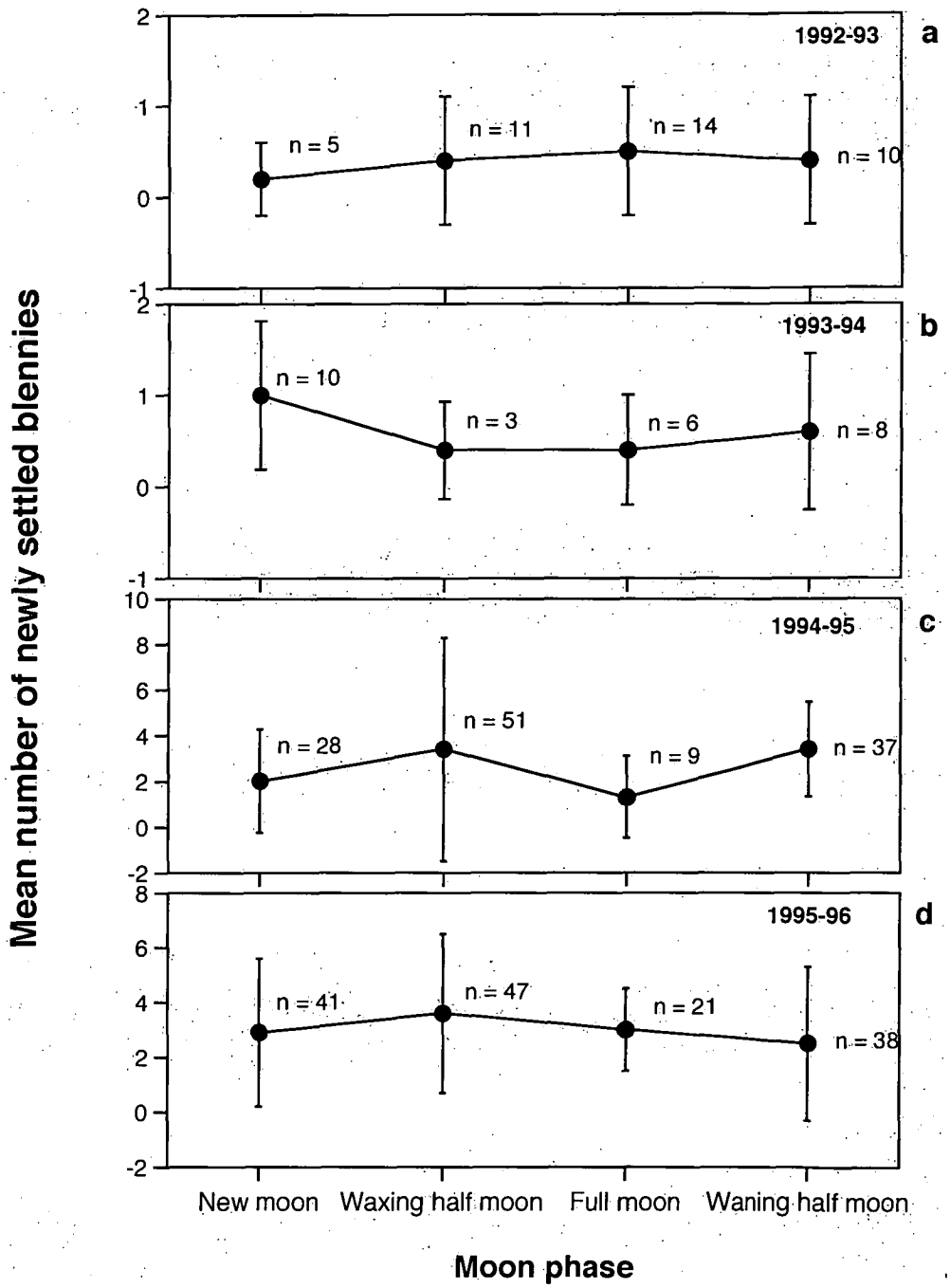

Figure 4.9. Mean number of newly settled blennies occurring during each lunar phase for individual years from 1992-93 to 1995-96 (a-d). Plots are based on data with information collected before or after the main peaks of settlement excluded; vertical lines = standard deviation.

Settlement - Excluding periods of low hatching

The frequency of settlement in relation to the lunar cycle, with periods when hatching was low or absent were removed, is shown in Figs. 4.10 and 4.11. Settlement exhibited significant periodicity in relation to moon phase ($P < 0.05$) when data were pooled for all 4 years with highest settlement occurring on waning half moons and low settlement occurring during full moon periods (Fig. 4.10). However, when data were pooled for only 2 years (1994-95 and 1995-96), there appeared to be no significant periodicity in relation to lunar phase ($P > 0.05$, Fig. 4.10) although there appeared to be a trend of low settlement on full moons and high settlement on waxing half moons (Fig. 4.10). For individual years, there appeared to be no significant periodicity in relation to lunar phase ($P > 0.05$, Fig. 4.11).

4.3.4 Effect of Wind on Hatching Dates and Settlement Variability

Hatching

Time series plots of apparent hatching dates in relation to south-easterly wind vectors (weekly maximum and weekly mean wind vector) are shown in Figs. 4.12a and 4.13a. Time series plots of this information for daily hatching data had a similar pattern to that of the combined weekly hatching but is more complex and is shown in Appendix 4.

Hatching - daily

Correlations between daily hatching data and the maximum south-easterly wind vector and the mean south-easterly wind vector are shown in Table 4.7 (at a lag of up to 7 d). When data were pooled across 4 years, hatching dates appeared to be negatively correlated to maximum south-easterly wind vector at a lag of 7 d only ($P < 0.05$) although there appeared to be no significant correlation at the same lag for the mean wind vector. When data were pooled for 2 years, there were apparently significant negative correlations at lags of 2 d with the maximum south-easterly wind vector ($P < 0.01$) and the mean south-easterly wind vector ($P < 0.05$). There also appeared to be a significant correlation between hatching and the mean south-easterly wind vector at a lag of 7 d ($P < 0.05$). Within years, there appeared to be significant correlation between hatching and the maximum south-easterly wind vector in 1992-93 at a lag of 6 d ($P < 0.05$), in 1994-95 at a lag of 2 d ($P < 0.01$), and in 1995-96 at a lag of 5 d ($P < 0.05$) and 7 d ($P < 0.05$). Significant correlation also appeared to exist between hatching and mean south-easterly wind vector in:

- 1994-95 at a lag of 1 d ($P < 0.05$) to 2 d ($P < 0.01$);

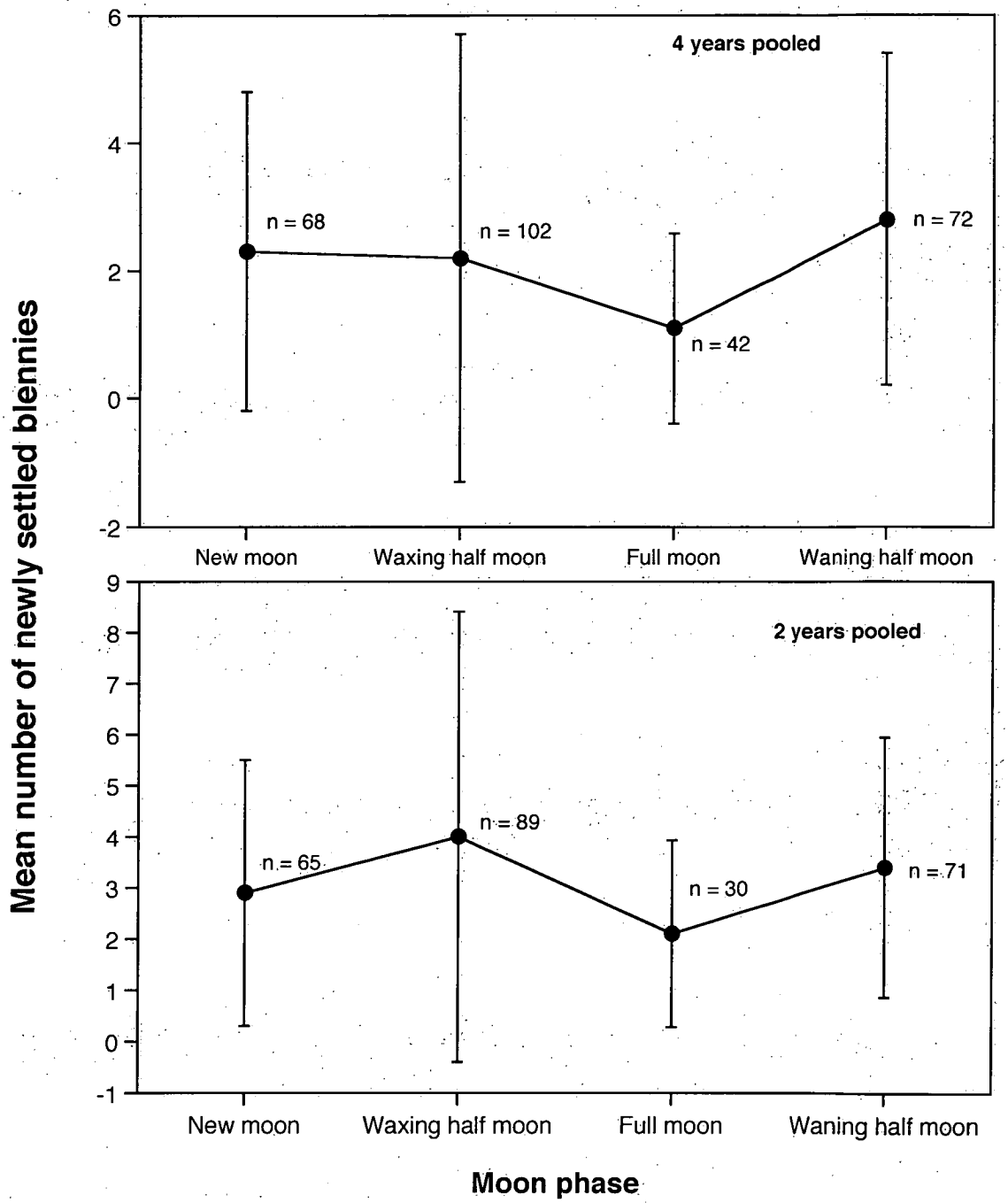

Figure 4.10. Mean number of newly settled blennies ocurring during each lunar phase when data were pooled for 4 years (top) and for 2 years (bottom). Plots are based on data screened to remove settlement data during periods where hatching was low; vertical lines = standard deviation.

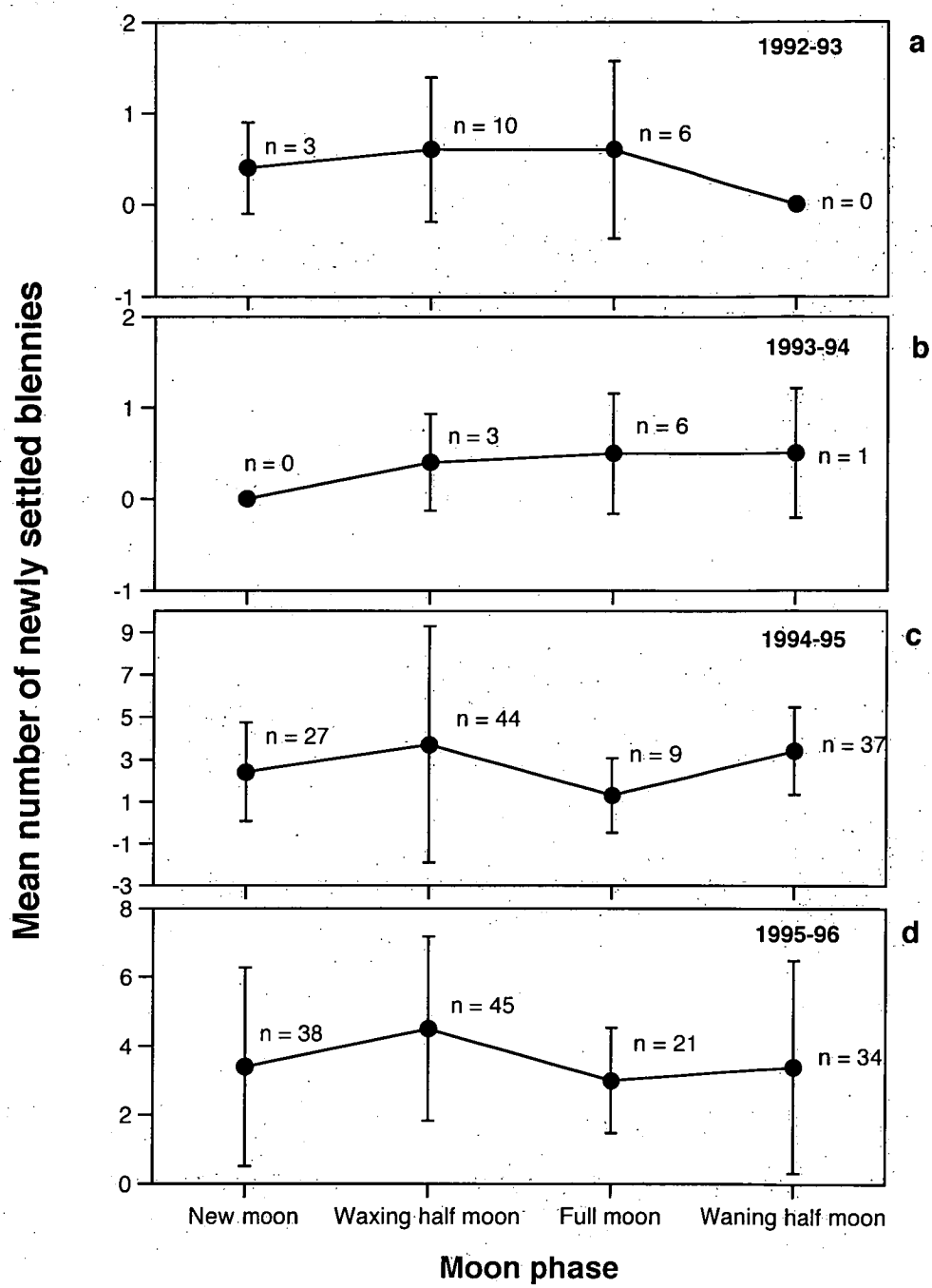

Figure 4.11. Mean number of newly settled blennies occurring during each lunar phase for individual years from 1992-93 to 1995-96 (a-d). Plots are based on data screened to remove settlement data during periods where hatching was low; vertical lines = standard deviation.

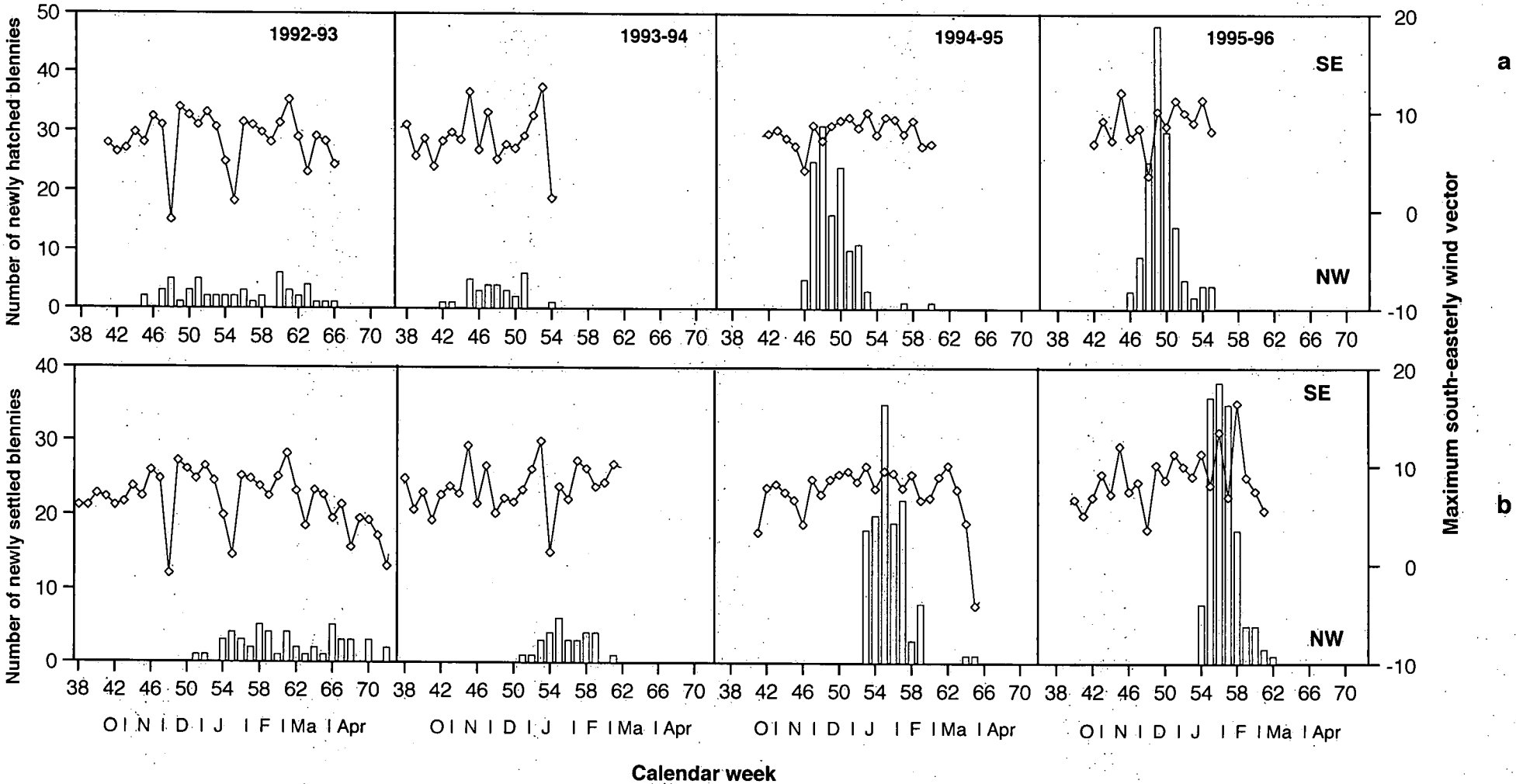

Figure 4.12. Weekly maximum south-easterly wind vector and number of newly hatched blennies (a) and number of newly settled blennies (b) during spring/summer from 1992-93 to 1995-96. Bar charts show number of newly hatched blennies and number of newly settled blennies pooled by calendar week; line charts show maximum south-easterly wind vector.

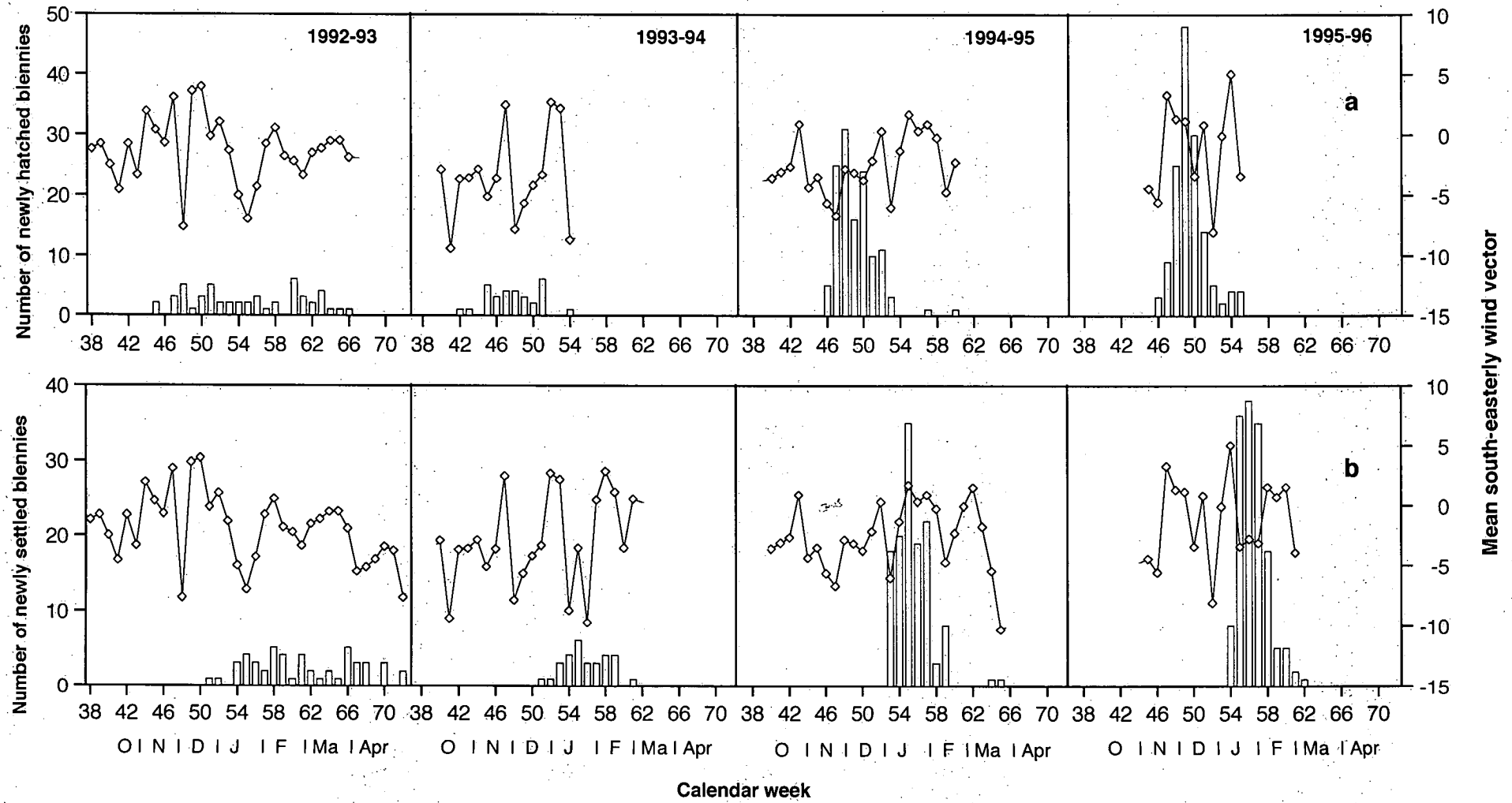

Figure 4.13. Mean weekly south-easterly wind vector and number of newly hatched blennies (a) and number of newly settled blennies pooled by week (b) during spring/summer from 1992-93 to 1995-96. Bar charts show number of newly hatched blennies and number of newly settled blennies; line charts show mean weekly south-easterly wind vector.

Table 4.7 Correlations (r) between back-calculated hatching dates and maximum and mean south-easterly wind vectors at reasonable lag of days up to 7 days. Data points collected before or after the main peak in hatching were excluded. *, ** : Correlation significant at $P < 0.05$, $P < 0.01$ respectively.

Physical factors	Day lag	4 Years pooled n = 228	1992-93 n = 100	1993-94 n = 49	2 Years (1994-95&1995-96) pooled; n = 79	1994-95 n = 46	1995-96 n = 33
Max. SE vector	0	- 0.03	- 0.05	0.02	- 0.03	- 0.04	- 0.07
	1	- 0.07	0.02	- 0.21	- 0.13	- 0.25	- 0.03
	2	- 0.08	0.07	0.01	- 0.29**	- 0.43**	- 0.18
	3	- 0.03	0.09	0.07	- 0.14	- 0.09	- 0.25
	4	- 0.04	0.12	0.03	- 0.15	- 0.09	- 0.29
	5	- 0.06	0.08	0.03	- 0.14	- 0.04	- 0.35*
	6	- 0.05	0.22*	- 0.18	- 0.08	0.003	- 0.28
	7	- 0.15*	- 0.08	- 0.20	- 0.18	- 0.09	- 0.39*
Mean SE vector	0	- 0.08	- 0.09	- 0.09	- 0.05	- 0.001	- 0.17
	1	- 0.12	- 0.003	- 0.19	- 0.19	- 0.33*	- 0.12
	2	- 0.09	0.09	0.004	- 0.26*	- 0.38**	- 0.20
	3	- 0.06	0.10	0.12	- 0.21	- 0.13	- 0.37*
	4	- 0.08	0.15	- 0.01	- 0.21	- 0.13	- 0.36*
	5	- 0.07	0.11	0.09	- 0.15	- 0.01	- 0.39*
	6	- 0.10	0.22	- 0.26	- 0.12	- 0.02	- 0.32
	7	- 0.19	- 0.04	- 0.18	- 0.25*	- 0.13	- 0.47**

• 1995-96 at a lag of 3 to 5 d ($P < 0.05$) and a lag of 7 d ($P < 0.01$).

No significant correlations with mean south-easterly wind vector emerged in 1992-93 or 1993-94 (Table 4.7).

Hatching - pooled by weeks

Correlations of hatching pooled by calendar week with weekly maximum and weekly mean south-easterly wind vector are shown in Table 4.8 (at lags of up to 4 w). When data were pooled for all 4 years, there appeared to be no correlation between weekly hatching and the maximum or mean south-easterly wind vector. When data for the two years 1994-95 and 1995-96 were pooled, there appeared to be significant correlation at a lag of 1 to 2 w with the maximum and mean south-easterly wind vector. No correlation was found within years in 1992-93 and 1994-95 while in 1993-94, there was negative correlation with the mean south-easterly wind vector at a lag of 3 w ($P < 0.01$). In 1995-96, there appeared to be a negative correlation with the maximum wind vector at a lag of 2 w ($P < 0.05$).

In summary, there appeared to be no consistent effect of maximum and mean wind vector on apparent hatching dates when analysed over both daily and weekly periods at a lag time of up to 7 d and up to 4 w respectively ($P > 0.05$).

Settlement

Time series plots of apparent settlement dates in relation to south-easterly wind vectors (weekly maximum and weekly mean wind vector) are shown in Figs. 4.12b and 4.13b. Time series plots of this information for daily settlement data had a similar pattern to that of the combined weekly settlement but is more complex and is shown in Appendix 5.

Settlement - daily

Correlations between the daily number of newly settled blennies and the maximum and mean south-easterly wind vector at a reasonable lag of days (7 d) are shown in Table 4.9 (data points outside the main settlement period were excluded). When data were pooled for all 4 years, there appeared to be no significant correlation with either maximum or mean south-easterly wind vector at any reasonable lag of days ($P > 0.05$). When data were pooled for 2 years, a negative correlation between the daily number of blennies settling and the mean south-easterly wind vector emerged at a lag of 5 d ($P < 0.05$). No significant correlations between

Table 4.8 Correlations (r) between back-calculated hatching dates and maximum and mean south-easterly wind vector at reasonable lag of weeks. Data points collected before or after the main peak in hatching were excluded. *, ** : Selection significant at $P < 0.05$, and $P < 0.01$, respectively.

Physical factors	Week lag	4 Years pooled n = 42	1992-93 n = 17	1993-94 n = 7	2 Years (1994-95&1995-96) pooled; n = 18	1994-95 n = 8	1995-96 n = 10
Max. SE vector	0	0.09	- 0.15	0.49	- 0.09	0.09	- 0.14
	1	- 0.04	0.15	- 0.11	- 0.55*	- 0.16	- 0.69*
	2	- 0.07	0.12	0.16	- 0.55*	- 0.68	- 0.46
	3	- 0.09	- 0.21	- 0.43	- 0.33	- 0.43	- 0.24
	4	0.17	0.46	0.05	- 0.07	- 0.50	0.15
Mean SE vector	0	- 0.11	- 0.12	0.25	- 0.31	0.18	- 0.43
	1	- 0.17	0.15	0.29	- 0.59**	- 0.58	- 0.60
	2	- 0.17	0.13	0.14	- 0.48*	- 0.63	- 0.42
	3	- 0.15	0.11	- 0.86**	- 0.29	- 0.52	- 0.12
	4	0.10	0.33	0.29	0.11	0.02	0.24

Table 4.9 Correlations (r) between daily settlement and maximum and mean south-easterly wind vectors at lag up to 7 days. Data points collected before or after the main peak in settlement were excluded. * : Correlation significant at $P < 0.05$.

Physical factors	Day lag	4 Years pooled n = 244	1992-93 n = 103	1993-94 n = 45	2 Years (1994-95&1995-96) pooled; n = 96	1994-95 n = 47	1995-96 n = 49
Max. SE vector	0	0.04	0.013	0.12	- 0.17	- 0.16	- 0.20
	1	0.04	- 0.03	0.18	- 0.15	- 0.17	- 0.15
	2	0.03	- 0.16	0.0003	- 0.07	0.01	- 0.19
	3	0.06	- 0.09	0.02	- 0.04	0.05	- 0.16
	4	0.04	0.05	- 0.09	- 0.14	- 0.19	- 0.12
	5	0.06	0.02	0.07	- 0.14	- 0.20	- 0.11
	6	0.09	- 0.07	0.06	- 0.03	- 0.13	0.04
	7	0.08	0.01	0.02	- 0.09	- 0.18	- 0.03
Mean SE vector	0	0.001	- 0.005	0.11	- 0.23	- 0.19	- 0.29
	1	0.002	- 0.05	0.16	- 0.22	- 0.20	- 0.26
	2	- 0.001	- 0.20	0.01	- 0.12	0.02	- 0.28
	3	0.04	- 0.09	0.06	- 0.102	0.06	- 0.29
	4	0.02	0.05	- 0.09	- 0.18	- 0.11	- 0.25
	5	0.03	0.03	0.02	- 0.20*	- 0.22	- 0.19
	6	0.06	- 0.03	0.08	- 0.12	- 0.14	- 0.11
	7	0.05	- 0.01	0.08	- 0.14	- 0.17	- 0.13

daily settlement and wind emerged for any year analysed separately ($P > 0.05$).

Settlement - pooled by weeks

Correlations of weekly settlement with wind at lags of up to 13 w are shown in Table 4.10 (maximum wind) and Table 4.11 (mean wind). When data were pooled for 4 years, there appeared to be significant positive correlation with the maximum wind vector at lags of 0, 1, and 2 w ($P < 0.05$) and significant positive correlation with the mean wind vector at a lag of 2 w ($P < 0.05$). When data were pooled for 2 years, there appeared to be significant negative correlation with the maximum wind vector at a lag of 9 w ($P < 0.05$) and with the mean wind vector at a lag of 12 w ($P < 0.01$). For separate years, there was no correlation between weekly settlement and the maximum wind vector in any year although significant correlations were detected with the mean wind vector in 1992-93, 1993-94, 1994-95, and 1995-96. These correlations occurred at differing weekly lags and were both negative and positive:

- in 1992-93, positive correlation occurred at a lag of 9 w ($P < 0.05$);
- in 1993-94, positive correlation occurred at a lag of 8 w ($P < 0.001$);
- in 1994-95, positive correlation occurred at a lag of 12 w ($P < 0.05$);
- and in 1995-96, negative correlation occurred at a lag of 0 w ($P < 0.05$) and positive correlation occurred at a lag of 4 w ($P < 0.05$).

In summary, when data points outside the main settlement period were excluded, there was no consistent significant effect of wind on settlement at any reasonable lag time when analysed over both daily and weekly periods ($P > 0.05$).

Settlement - daily - Excluding Periods of Low hatching

Additional analyses by stepwise multiple regression were conducted after exclusion of data from periods where hatching was low or absent.

When data were pooled for all 4 years, there was no correlation between settlement and maximum or mean wind vectors at any reasonable lag of days (Table 4.12). However, when data were pooled for 2 years, there appeared to be significant negative correlation with the mean south-easterly wind vector at a lag of 0 to 1 d ($P < 0.05$). Within separate years, there was correlation with wind vector strength in 1992-93 and 1995-96 but on different days lag and of differing patterns without consistency (negative or positive correlation). For example, in 1992-93, there

Table 4.10 Correlations (r) between weekly settlement and maximum south-easterly wind vector at reasonable week lags. Periods of low settlement before and after the main peak were excluded. * : Correlation significant at $P < 0.05$.

Physical factors	Week lag	4 Years pooled n = 38	1992-93 n = 17	1993-94 n = 7	2 Years (1994-95&1995-96) pooled; n = 14	1994-95 n = 7	1995-96 n = 7
Maximum SE	0	0.38*	0.005	- 0.29	0.15	0.18	0.15
	1	0.37*	0.25	- 0.49	- 0.07	0.24	- 0.17
	2	0.37*	0.09	0.72	- 0.11	0.23	- 0.23
	3	0.30	- 0.10	0.29	- 0.15	- 0.42	- 0.10
	4	0.27	- 0.29	- 0.34	0.13	0.62	- 0.03
	5	0.29	0.27	- 0.12	- 0.04	- 0.24	0.05
	6	0.30	0.23	- 0.10	0.16	- 0.11	0.25
	7	0.03	- 0.12	- 0.03	- 0.31	- 0.36	- 0.31
	8	- 0.05	- 0.06	0.20	- 0.45	- 0.39	- 0.51
	9	- 0.04	0.23	- 0.12	- 0.63*	- 0.72	- 0.66
	10	0.05	0.03	0.45	- 0.04	- 0.17	0.01
	11	- 0.03	- 0.33	- 0.20	0.06	- 0.43	0.28
	12	0.13	0.05	- 0.005	0.50	0.37	0.61
	13	- 0.09	- 0.42	- 0.05	0.17	0.19	0.17

Table 4.11 Correlations (r) between weekly settlement and mean south-easterly wind vector at lags up to 13 weeks. Low settlement period before and after the main settlement peak were excluded. *, **, *** : Selection significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$ respectively.

Physical factors	Week lag	4 Years pooled n = 38	1992-93 n = 17	1993-94 n = 7	2 Years (1994-95&1995-96) pooled; n = 14	1994-95 n = 7	1995-96 n = 7
Mean SE	0	0.13	- 0.10	- 0.05	- 0.31	0.25	- 0.78*
	1	0.20	0.16	- 0.18	- 0.32	- 0.29	- 0.35
	2	0.33*	0.22	0.53	0.01	- 0.51	0.33
	3	0.27	- 0.07	0.36	0.17	- 0.47	0.54
	4	0.21	- 0.03	- 0.37	0.37	- 0.42	0.80*
	5	0.11	0.03	- 0.12	0.12	0.47	- 0.01
	6	- 0.05	0.07	- 0.27	- 0.19	- 0.33	- 0.20
	7	- 0.20	- 0.03	- 0.11	- 0.50	- 0.47	- 0.64
	8	- 0.11	0.36	0.95***	- 0.40	- 0.47	- 0.47
	9	- 0.12	0.49*	- 0.17	- 0.33	- 0.45	- 0.40
	10	- 0.18	- 0.03	- 0.48	- 0.01	- 0.21	0.08
	11	- 0.03	- 0.18	0.17	0.29	0.36	0.29
	12	0.10	0.06	0.34	0.68**	0.80*	0.68
	13	- 0.03	- 0.26	- 0.24	0.27	0.31	0.27

Table 4.12 Correlations (r) between daily settlement and maximum and mean south-easterly wind vector at reasonable lag of days. Settlement periods where hatching was low were excluded from analyses. * : Correlation significant at $P < 0.05$.

Physical factors	Day lag	4 Years pooled n = 143	1992-93 n = 42	1993-94 n = 22	2 Years (1994-95&1995-96) pooled; n = 79	1994-95 n = 41	1995-96 n = 38
Max. SE vector	0	0.06	0.35*	0.06	- 0.16	- 0.13	- 0.23
	1	- 0.01	- 0.09	0.03	- 0.16	- 0.14	- 0.22
	2	0.01	- 0.22	0.04	- 0.06	0.02	- 0.21
	3	0.06	- 0.23	0.22	0.03	0.11	- 0.12
	4	0.04	0.19	- 0.14	- 0.09	- 0.18	- 0.03
	5	0.03	0.08	0.005	- 0.10	- 0.21	- 0.01
	6	0.09	- 0.09	0.32	0.02	- 0.09	0.11
	7	0.01	- 0.08	- 0.06	- 0.08	- 0.24	0.05
Mean SE vector	0	- 0.005	0.28	0.06	- 0.24*	- 0.19	- 0.36*
	1	- 0.05	- 0.06	- 0.0004	- 0.22*	- 0.17	- 0.31*
	2	- 0.03	- 0.37*	0.08	- 0.10	0.04	- 0.30
	3	0.02	- 0.27	0.22	- 0.03	0.14	- 0.27
	4	0.03	0.18	- 0.02	- 0.12	- 0.06	- 0.22
	5	0.0002	0.15	- 0.10	- 0.14	- 0.21	- 0.10
	6	0.05	0.03	0.23	- 0.06	- 0.09	- 0.03
	7	0.02	- 0.12	0.16	- 0.11	- 0.20	- 0.02

appeared to be significant positive correlation with the maximum wind vector at a lag of 0 d ($P < 0.05$) and significant negative correlation with the mean wind vector at a lag of 2 d ($P < 0.05$). Consequently, these statistical results are presumed to be spurious.

Settlement - weekly - Excluding Periods of Low hatching

The correlations between settlement and weekly maximum and mean wind vectors are shown in Table 4.13 and 4.14; periods of settlement data where hatching was low or absent were excluded from these analyses. When data were pooled for all 4 years, there appeared to be significant positive correlation with the maximum wind vector at lag of 0 to 3 w (Table 4.13), and significant positive correlation with the mean wind vector at a lag of 2 w (Table 4.14). When data in the 2 years with high settlement were pooled, there appeared to be both positive and negative correlation with maximum wind vector at lags of 4 w and 9 w ($P < 0.05$, Table 4.13). A significant positive correlation with the mean south-easterly wind vector also emerged at a lag of 12 w ($P < 0.05$, Table 4.14). Within separate years, no correlation with maximum wind vector occurred although there was correlation with the mean wind vector in:

- 1992-93 at a lag of 9 w ($P < 0.05$, Table 4.14);
- 1993-94 at a lag of 8 w ($P < 0.01$, Table 4.14);
- 1994-95 at a lag of 12 w ($P < 0.05$, Table 4.14);
- and in 1995-96 at a lag of 0 w ($P < 0.05$, Table 4.14).

These correlations were both negative and positive over varying lags without consistency. Consequently, these statistical results are presumed to be spurious.

In summary, no significant effect of wind vector on settlement was detected when data were grouped by either daily or weekly periods ($P > 0.05$).

4.3.5 Effect of Rainfall on Hatching Dates and Settlement Variability

The pattern of daily rainfall with hatching and subsequent settlement is shown in Appendix 6 and 7, and the pattern of weekly rainfall with hatching and settlement is shown in Figs. 4.14a and 4.14b respectively. Rainfall during the sampling period differed markedly between years with heaviest rainfall in 1993-94 (mean = 2.4 ± 7.8 mm) and 1995-96 (mean = 2.9 ± 8.9

Table 4.13 Correlations (r) between weekly settlement and maximum south-easterly wind vector at reasonable lag of weeks. Settlement periods where hatching was low were excluded. *, ** : Selection significant at $P < 0.05$, and $P < 0.01$, respectively.

Physical factors	Week lag	4 Years pooled n = 33	1992-93 n = 14	1993-94 n = 6	2 Years (1994-95&1995-96) pooled; n = 13	1994-95 n = 7	1995-96 n = 6
Maximum SE	0	0.40*	0.03	- 0.29	0.08	0.18	- 0.04
	1	0.35*	0.37	- 0.52	- 0.12	0.24	- 0.34
	2	0.43**	0.09	0.73	0.27	0.23	0.28
	3	0.35*	0.003	0.31	- 0.39	- 0.42	- 0.63
	4	0.32	- 0.35	- 0.35	0.61*	0.62	0.62
	5	0.32	0.17	- 0.07	- 0.15	- 0.24	- 0.36
	6	0.36	0.19	- 0.26	0.34	- 0.11	0.55
	7	0.07	- 0.14	- 0.11	- 0.31	- 0.36	- 0.33
	8	- 0.11	0.02	0.20	- 0.39	- 0.39	- 0.46
	9	- 0.11	0.22	- 0.10	- 0.56*	- 0.72	- 0.58
	10	0.03	- 0.04	0.49	0.005	- 0.17	0.06
	11	- 0.05	- 0.20	- 0.17	0.21	- 0.43	0.55
	12	0.17	0.13	- 0.05	0.40	0.37	0.40
	13	- 0.09	- 0.47	- 0.03	0.26	0.19	0.25

Table 4.14 Correlations (r) between weekly settlement and mean south-easterly wind vector at a reasonable lag of weeks. Settlement periods where hatching was low were excluded. *, ** : Selection significant at $P < 0.05$, and $P < 0.01$, respectively.

Physical factors	Week lag	4 Years pooled n = 33	1992-93 n = 14	1993-94 n = 6	2 Years (1994-95&1995-96) pooled; n = 13	1994-95 n = 7	1995-96 n = 6
Mean SE	0	0.15	- 0.12	- 0.08	- 0.25	0.25	- 0.80*
	1	0.22	0.18	- 0.24	- 0.31	- 0.29	- 0.38
	2	0.33*	0.22	0.53	0.09	- 0.51	0.48
	3	0.27	- 0.13	0.52	0.09	- 0.47	0.41
	4	0.22	- 0.07	- 0.37	0.34	- 0.42	0.78
	5	0.10	0.09	- 0.09	0.05	0.47	- 0.34
	6	- 0.002	0.06	- 0.35	- 0.03	- 0.33	0.01
	7	- 0.17	- 0.06	- 0.22	- 0.40	- 0.47	- 0.52
	8	- 0.15	0.45	0.95**	- 0.33	- 0.47	- 0.43
	9	- 0.15	0.53*	- 0.16	- 0.13	- 0.45	- 0.11
	10	- 0.22	0.03	- 0.48	- 0.09	- 0.21	- 0.12
	11	- 0.03	- 0.06	0.31	0.39	0.36	0.38
	12	0.16	0.15	0.41	0.62*	0.80*	0.53
	13	- 0.02	- 0.26	- 0.24	0.42	0.31	0.47

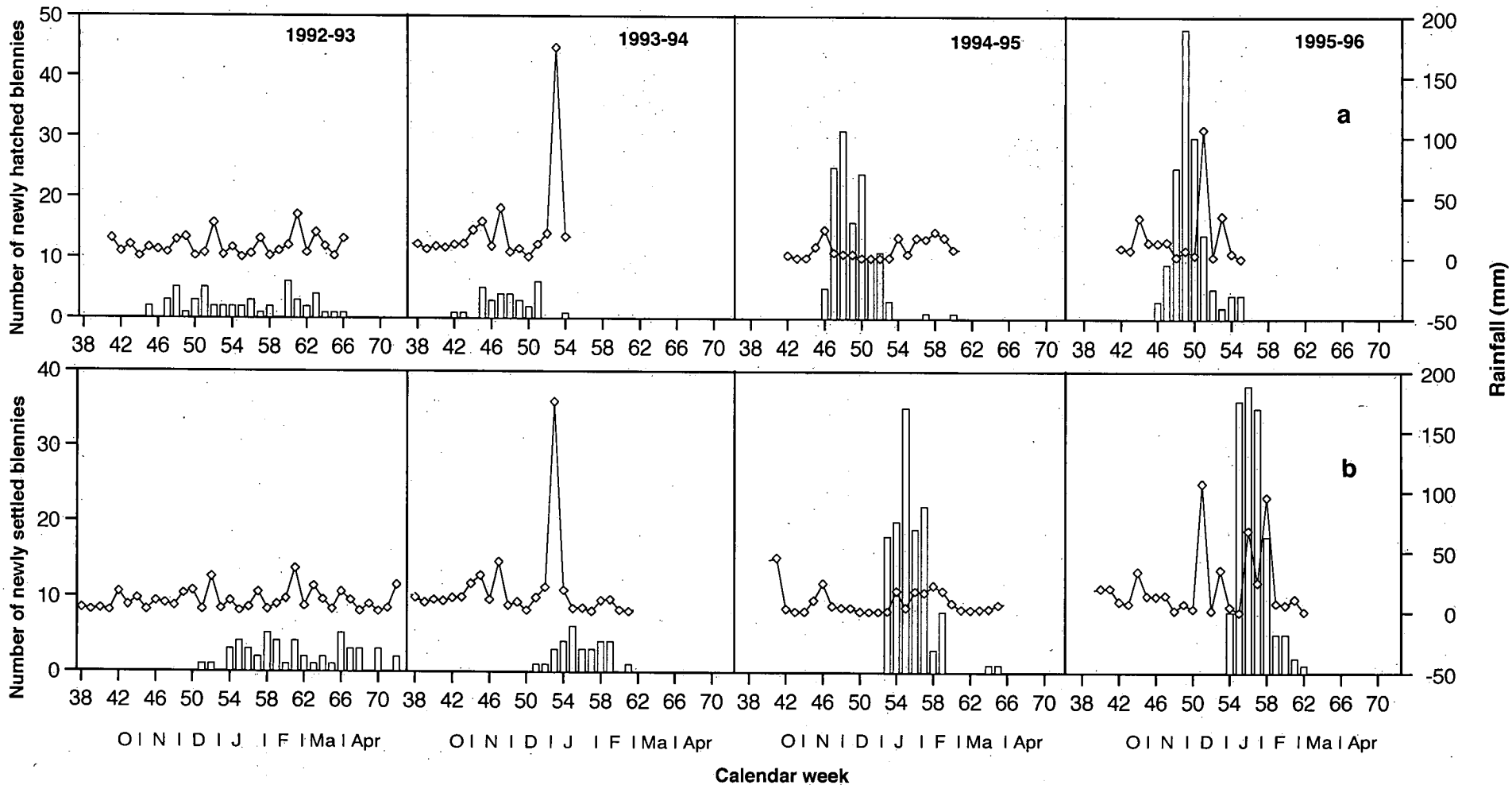

Figure 4.14. Patterns of weekly rainfall and number of newly hatched blennies (a) and number of newly settled blennies (b) during spring/summer from 1992-93 to 1995-96. Bar charts show number of newly hatched blennies and number of newly settled blennies pooled by calendar week; line charts show rainfall pooled by week.

mm). Rainfall in 1992-93 was relatively uniform whereas in 1993-94 and 1995-96 a major peak occurred during December.

Hatching daily

Correlations between daily hatching and daily rainfall at a reasonable lag of days are shown in Table 4.15. When data were pooled for all 4 years, there appeared to be no correlation at any reasonable lag of days. When data were pooled over 2 years (1994-95 and 1995-96) there appeared to be significant negative correlation between rainfall and hatching at a lag of 5 d ($P < 0.05$). Within separate years, significant correlation occurred only in 1995-96 at lag of 4 to 5 d ($P < 0.05$ and $P < 0.01$ respectively).

Hatching - weekly

Correlation of weekly hatching and rainfall at any reasonable lag of weeks are shown in Table 4.16. There appeared to be no significant correlations when data were pooled for either 4 years or for 2 years. Within years, there appeared to be a significant positive correlation with rainfall at a lag of 2 w in 1994-95 ($P < 0.05$).

Settlement - daily

There were no significant correlations of daily settlement with rainfall at any reasonable lag of days when data were pooled for either 4 years or for 2 years or within separate years ($P > 0.05$, Table 4.17).

Settlement - weekly

Correlations of weekly settlement with rainfall at any reasonable lag of weeks are shown in Table 4.18. There was no significant correlation when data were pooled for either 4 years or 2 years. Within separate years, there appeared to be significant correlation in:

- 1992-93 at a lag of 8 w ($P < 0.001$);
- 1993-94 at a lag of 2 w ($P < 0.05$);
- and in 1994-95 at a lag of 4 weeks ($P < 0.01$).

In summary, there was no consistent effect of rainfall on settlement when data were analysed by multiple regression (after points before or after main peak were removed) for both daily and weekly periods ($P > 0.05$).

Table 4.15 Correlations (r) between daily back-calculated hatching dates and rainfall at reasonable lag of days. Data points collected before or after the main peak in hatching were excluded. *, ** : Correlation significant at $P < 0.05$, $P < 0.01$, respectively.

Physical factors	Day lag	4 Years pooled n = 228	1992-93 n = 100	1993-94 n = 49	2 Years (1994-95&1995-96) pooled; n = 79	1994-95 n = 46	1995-96 n = 33
Rainfall	0	- 0.05	- 0.04	- 0.22	- 0.06	0.05	- 0.18
	1	- 0.03	0.19	- 0.08	- 0.14	0.20	- 0.32
	2	0.01	0.15	0.12	- 0.13	0.07	- 0.29
	3	- 0.01	0.03	0.08	- 0.15	0.02	- 0.31
	4	- 0.04	- 0.04	0.09	- 0.20	- 0.08	- 0.37*
	5	- 0.08	- 0.02	- 0.05	- 0.23*	0.02	- 0.45**
	6	- 0.01	- 0.02	- 0.12	- 0.06	- 0.03	- 0.16
	7	- 0.01	- 0.02	- 0.03	- 0.03	0.14	- 0.12

Table 4.16 Correlations (r) between weekly back-calculated hatching dates and rainfall at reasonable lag of weeks. Data points collected before or after the main peak in hatching were excluded. * : Correlation significant at $P < 0.05$.

Physical factors	Week lag	4 Years pooled n = 42	1992-93 n = 17	1993-94 n = 7	2 Years (1994-95&1995-96) pooled; n = 18	1994-95 n = 8	1995-96 n = 10
Rainfall	0	- 0.003	0.06	0.47	- 0.08	- 0.31	- 0.001
	1	- 0.08	- 0.09	0.003	- 0.21	0.35	- 0.26
	2	- 0.14	0.10	- 0.18	- 0.38	0.70*	- 0.53
	3	0.01	0.21	- 0.62	- 0.12	0.37	- 0.13
	4	0.06	0.12	0.46	- 0.08	0.24	- 0.07

Table 4.17 Correlations (r) between daily settlement and rainfall at reasonable lag of days. Data points collected before or after the main peak in settlement were excluded. * : Correlation significant at $P < 0.05$.

Physical factor	Day lag	4 Years pooled n = 244	1992-93 n = 103	1993-94 n = 45	2 Years (1994-95&1995-96) pooled; n = 96	1994-95 n = 47	1995-96 n = 49
Rainfall	0	0.07	0.07	0.02	0.03	0.08	0.001
	1	0.08	- 0.04	0.17	0.05	0.07	0.03
	2	0.05	- 0.07	- 0.12	0.09	0.12	0.08
	3	- 0.01	- 0.10	- 0.12	- 0.02	- 0.06	- 0.03
	4	- 0.07	- 0.11	- 0.16	- 0.12	- 0.15	- 0.15
	5	- 0.05	0.02	- 0.23	- 0.07	- 0.23	- 0.06
	6	0.09	0.14	0.16	0.04	- 0.09	0.07
	7	0.03	0.08	0.17	- 0.06	- 0.31	- 0.04

Table 4.18 Correlations (r) between weekly settlement and rainfall at reasonable lag of weeks. Data points collected before or after the main peak in settlement were excluded. *, **, ***: Selection significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$ respectively.

Physical factor	Week lag	4 Years pooled n = 38	1992-93 n = 17	1993-94 n = 7	2 Years (1994-95&1995-96) pooled; n = 14	1994-95 n = 7	1995-96 n = 7
Rainfall	0	0.14	0.02	- 0.35	0.21	- 0.60	0.39
	1	0.06	0.08	0.14	- 0.26	- 0.30	- 0.34
	2	0.02	- 0.22	0.81*	- 0.35	- 0.71	- 0.42
	3	- 0.08	- 0.15	- 0.31	- 0.40	- 0.21	- 0.59
	4	0.04	0.01	- 0.38	0.08	- 0.90**	0.22
	5	0.08	0.13	0.04	0.29	- 0.31	0.44
	6	0.02	- 0.02	0.04	0.20	0.49	0.24
	7	0.10	0.37	0.13	- 0.03	0.26	- 0.11
	8	- 0.14	- 0.76***	0.51	- 0.29	0.39	- 0.49
	9	- 0.01	0.26	- 0.36	- 0.24	0.56	- 0.46
	10	0.02	0.24	0.14	0.18	0.25	0.11
	11	- 0.05	- 0.26	0.17	0.19	0.09	0.35
	12	- 0.02	0.20	- 0.22	- 0.05	- 0.31	0.67
	13	0.14	0.01	- 0.12	- 0.05	- 0.05	- 0.06

Settlement - Excluding Periods of Low hatching

Additional analyses by multiple regression were conducted after screening data to remove periods of low larval supply.

Correlations between adjusted daily settlement data and rainfall are shown in Table 4.19. There were no significant correlations for data pooled over either 4 years or 2 years ($P > 0.05$). Within years, there was significant correlation only in 1992-93 at a lag of 6 d ($P < 0.05$).

Correlations between adjusted weekly settlement data and rainfall are shown in Table 4.20. There were no significant correlations for data pooled over either 4 years or 2 years ($P > 0.05$). Within separate years, there appeared to be correlation in:

- 1992-93 at a lag of 8 w ($P < 0.001$);
- in 1993-94 at a lag of 2 w ($P < 0.05$);
- and in 1994-95 at a lag of 4 w ($P < 0.01$).

These correlations were both negative and positive over varying lags without consistency (Table 4.20). Consequently, these statistical results are presumed to be spurious.

In summary, there appeared to be no significant effect of rainfall on settlement over both daily and weekly lag periods ($P > 0.05$).

4.3.6 Effect of River Discharge on Hatching Dates and Settlement Variability

Hatching

The pattern of weekly river discharge of the Derwent River at Meadowbank in relation to weekly frequency of newly hatched blennies is shown in Fig. 4.15a (daily pattern is presented in Appendix 8).

Correlations between daily hatching and river discharge at reasonable lags of days are shown in Table 4.21 and correlations between weekly hatching and river discharge at reasonable lags of weeks are shown in Table 4.22.

When data were pooled across 4 years, there was significant correlation at a lag of 3 to 7 d (Table 4.21) and significant correlation emerged at lags of 0 to 3 w (Table 4.22). When data were pooled for 2 years, there appeared

Table 4.19 Correlations (r) between daily settlement and rainfall at a reasonable lag of days. Settlement periods where hatching was low were excluded. * : Correlation significant at $P < 0.05$.

Physical factors	Day lag	4 Years pooled n = 143	1992-93 n = 42	1993-94 n = 22	2 Years (1994-95&1995-96) pooled; n = 79	1994-95 n = 41	1995-96 n = 38
Rainfall	0	0.01	0.03	0.09	- 0.02	- 0.01	- 0.08
	1	0.04	- 0.01	0.35	0.04	0.20	- 0.03
	2	- 0.02	- 0.10	- 0.10	0.15	0.12	0.17
	3	- 0.06	- 0.13	- 0.11	0.06	- 0.01	0.07
	4	- 0.08	- 0.23	- 0.13	0.01	- 0.16	0.05
	5	0.01	0.005	- 0.18	0.12	- 0.16	0.22
	6	0.17	0.30*	0.08	0.18	- 0.08	0.29
	7	0.04	0.14	- 0.07	0.004	- 0.27	0.08

Table 4.20 Correlations (r) between weekly settlement and rainfall at reasonable lag of weeks. Settlement periods with low hatching were excluded). *, **, ***: Correlation significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.

Physical factor	Week lag	4 Years pooled n = 33	1992-93 n = 14	1993-94 n = 6	2 Years (1994-95&1995-96) pooled; n = 13	1994-95 n = 7	1995-96 n = 6
Rainfall	0	0.12	- 0.02	- 0.35	0.16	- 0.60	0.30
	1	0.05	0.22	0.16	- 0.34	- 0.30	- 0.63
	2	0.01	- 0.24	0.86*	- 0.13	- 0.71	- 0.05
	3	- 0.07	- 0.30	- 0.31	- 0.41	- 0.21	- 0.75
	4	0.04	0.01	- 0.38	0.30	- 0.90**	0.53
	5	0.07	- 0.07	0.05	0.27	- 0.31	0.38
	6	0.07	- 0.001	- 0.28	0.18	0.49	0.16
	7	0.12	0.44	0.11	0.05	0.26	- 0.05
	8	- 0.16	- 0.79***	0.54	- 0.37	0.39	- 0.72
	9	- 0.05	0.24	- 0.36	0.48	0.56	0.34
	10	0.003	0.31	0.19	0.07	0.25	- 0.34
	11	- 0.09	- 0.22	0.25	0.30	0.09	0.64
	12	0.03	- 0.25	- 0.47	- 0.09	- 0.31	0.67
	13	0.11	0.07	- 0.10	- 0.17	- 0.05	- 0.72

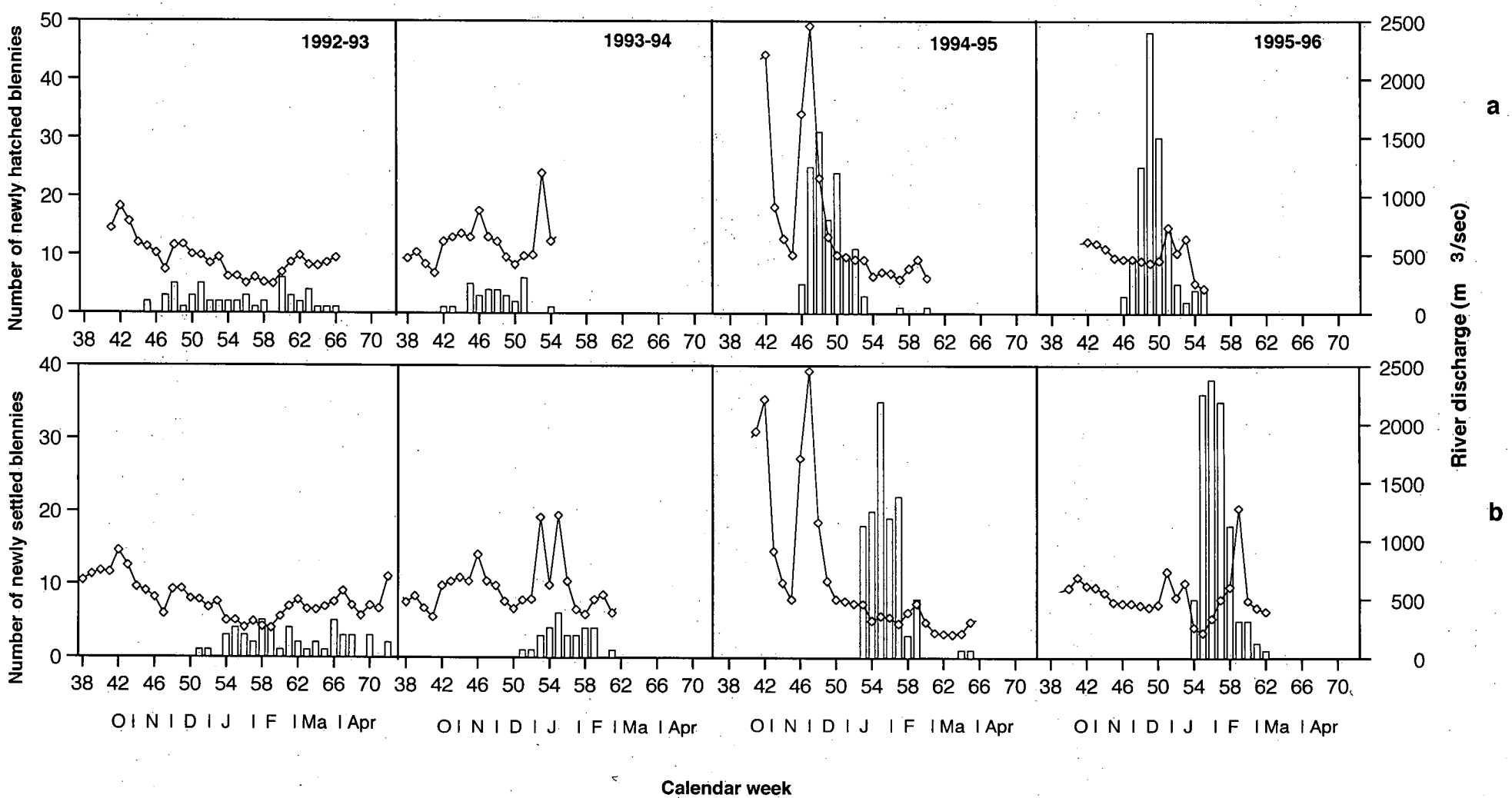

Figure 4.15. Weekly river discharge and number of newly hatched blennies (a) and number of newly settled blennies (b) during spring/summer from 1992-93 to 1995-96. Bar charts show number of newly hatched blennies and newly settled blennies pooled by calendar week; line charts show river discharge pooled by calendar week.

Table 4.21 Correlations (r) between back-calculated hatching dates and river discharge at a reasonable lag of days. Data points collected before or after the main peak in hatching were excluded. *, **, ***, **** : Selection significant at $P < 0.05$, $P < 0.01$, $P < 0.001$, and $P < 0.0001$, respectively.

Physical factors	Day lag	4 Years pooled n = 228	1992-93 n = 100	1993-94 n = 49	2 Years (1994-95&1995-96) pooled; n = 79	1994-95 n = 46	1995-96 n = 33
River discharge	0	0.29	0.10	0.01	0.03	0.24	- 0.46**
	1	0.29	0.04	0.06	0.02	0.25	- 0.49**
	2	0.29	- 0.06	0.10	0.02	0.26	- 0.52*
	3	0.31****	- 0.04	- 0.02	0.06	0.30*	- 0.43**
	4	0.31****	- 0.18	0.04	0.10	0.34*	- 0.26
	5	0.33****	- 0.08	0.09	0.14	0.39**	- 0.19
	6	0.35****	0.005	0.02	0.18	0.45**	- 0.22
	7	0.37****	0.11	- 0.05	0.23*	0.51**	- 0.30

Table 4.22 Correlations (r) between weekly back-calculated hatching dates and river discharge at reasonable lag of weeks. Data points collected before or after the main peak in hatching were excluded. *, ** : Selection significant at $P < 0.05$, and $P < 0.01$, respectively.

Physical factor	Week lag	4 Years pooled n = 42	1992-93 n = 17	1993-94 n = 7	2 Years (1994-95&1995-96) pooled; n = 18	1994-95 n = 8	1995-96 n = 10
River discharge	0	0.37**	0.32	0.11	0.21	0.25	0.08
	1	0.47**	0.16	0.04	0.39	0.73*	- 0.24
	2	0.39**	0.30	- 0.21	0.23	0.47	- 0.69*
	3	0.38**	0.28	- 0.37	0.19	0.30	- 0.39
	4	0.25	- 0.05	- 0.63	- 0.01	- 0.24	- 0.19

to be correlation at a lag of 7 d ($P < 0.05$, Table 4.21) but there appeared to be no correlation at any reasonable lag of weeks (Table 4.22). Within separate years, correlation with river discharge were observed although these were not consistent; there appeared to be significant positive correlation in 1994-95 at lag of 3 to 7 d and significant negative correlation in 1995-96 at lag of 0 to 3 d (Table 4.21). For weekly data, there appeared to be significant correlation in 1994-95 at a lag of 1 w and in 1995-96 at a lag of 2 w ($P < 0.05$, Table 4.22). These correlations were not consistent between years over varying lags. Consequently, these statistical results are presumed to be spurious.

In summary, there appeared to be no significant effect of river discharge on hatching over both daily ($P > 0.05$) and weekly lag periods ($P > 0.05$).

Settlement

The weekly pattern of river discharge of the Derwent River at Meadow Bank in relation to frequency of newly settled blennies is shown in Fig. 4.15b (the daily pattern in relation to newly settled blennies is shown in Appendix 9).

Correlations between the daily settlement and river discharge at a reasonable lag of days are shown in Table 4.23 (data screened to remove periods before or after the peaks periods for settlement). When data were pooled across 4 years, there appeared to be significant negative correlation at a lag of 6 to 7 d ($P < 0.05$). When data for the 2 years with high settlement were pooled, there appeared to be significant correlation from lag of 0 to 7 d ($P < 0.05$). Within separate years, there was correlation between daily settlement and river discharge only in 1995-96 at a lag of 0 to 7 d.

Correlation of weekly settlement with river discharge at a reasonable lag of weeks is shown in Table 4.24 (data screened to remove periods before or after the peaks periods for settlement). In analysis of other physical factors, correlations were assessed for lags of up to 13 weeks, however, for river discharge, correlations were only assessed for 10 weeks lag due to lack of river flow data for the remaining 3 weeks. When data were pooled for all 4 years, there appeared to be correlation at a lag of 5 to 10 w. When data were pooled for 2 years, there appeared to be significant correlations at lags of 1 w ($P < 0.05$) and 4 w ($P < 0.01$). Within separate years, significant correlation emerged only in 1995-96 at a lag of 1 w ($P < 0.05$) and at lags of 4 to 5 w ($P < 0.05$).

Table 4.23 Correlations (r) between daily settlement and river discharge at a reasonable lag of days. Data points collected before or after the main peak in settlement were excluded. *, **, ***, **** : Selection significant at $P < 0.05$, $P < 0.01$, $P < 0.001$, and $P < 0.0001$, respectively.

Physical factor	Day lag	4 Years pooled n = 244	1992-93 n = 103	1993-94 n = 45	2 Years (1994-95&1995-96) pooled; n = 96	1994-95 n = 47	1995-96 n = 49
River discharge	0	- 0.09	- 0.11	0.03	- 0.22*	- 0.11	- 0.34**
	1	- 0.13	- 0.06	- 0.03	- 0.28**	0.01	- 0.45**
	2	- 0.09	- 0.005	0.17	- 0.29**	0.05	- 0.48**
	3	- 0.12	- 0.07	0.01	- 0.28**	0.06	- 0.47**
	4	- 0.11	- 0.02	0.03	- 0.28**	- 0.03	- 0.45**
	5	- 0.13	- 0.05	0.02	- 0.31**	0.12	- 0.52**
	6	- 0.13*	- 0.01	- 0.01	- 0.30**	0.04	- 0.48**
	7	- 0.12*	- 0.04	0.10	- 0.33**	0.14	- 0.56****

Table 4.24 Correlations (r) between weekly settlement and river discharge at a reasonable lag of weeks. Data points before or after the main peak in settlement were excluded. *, ** : Correlation significant at $P < 0.05$, and $P < 0.01$, respectively. No data of river discharge at lags of 11 to 13 weeks were available.

Physical factor	Week lag	4 Years pooled n = 38	1992-93 n = 17	1993-94 n = 7	2 Years (1994-95&1995-96) pooled; n = 14	1994-95 n = 7	1995-96 n = 7
River discharge	0	- 0.09	- 0.08	0.32	- 0.41	- 0.40	- 0.53
	1	- 0.15	- 0.18	- 0.19	- 0.54*	0.29	- 0.83*
	2	- 0.11	- 0.39	0.31	- 0.21	0.53	- 0.53
	3	- 0.02	- 0.16	- 0.21	0.07	0.51	- 0.07
	4	0.19	0.17	- 0.20	0.71**	0.67	0.76*
	5	0.35*	0.32	- 0.04	0.46	0.26	0.79*
	6	0.35*	0.37	0.06	0.17	0.23	0.28
	7	0.42**	0.05	0.01	0.18	0.42	- 0.39
	8	0.45**	0.13	0.15	0.29	0.65	- 0.66
	9	0.42**	0.27	0.38	0.19	0.47	- 0.51
	10	0.34*	0.36	- 0.34	0.01	0.05	- 0.01

In summary, there appeared to be no significant effect of river discharge on settlement when analysed for either daily or weekly periods ($P > 0.05$).

Settlement - Excluding Periods of Low hatching

In additional analyses, data were screened to remove settlement periods with low larval supply. Correlations between daily settlement and river discharge at reasonable daily lags are shown in Table 4.25. When data were pooled across 4 years, there appeared to be correlation at lags of 1 d and from 3 to 7 d. When data were pooled for 2 years, significant correlation emerged at lags of 3 to 7 d. Within separate years, there appeared to be correlation only in 1995-96 at lag of 2 to 7 d.

Correlations between weekly settlement and river discharge at reasonable weekly lags are shown in Table 4.26. When data were pooled across all 4 years, there appeared to be significant correlations at lags from 5 to 10 w. When data were pooled for 2 years, there appeared to be significant correlation at a lag of 4 w ($P < 0.01$). Within separate years, significant correlation occurred in 1992-93 at a lag of 10 w ($P < 0.05$), and in 1995-96 at a lag of 1 w ($P < 0.01$).

In summary, there appeared to be no consistent effect of river discharge on settlement when analysed by multiple regression for: week pooled across year ($P > 0.05$), week within years at reasonable lags ($P > 0.05$), and for daily data ($P > 0.05$).

There were two high discharge peaks in 1993-94 during December and January, during which little settlement occurred. Another peak during February in 1995-96 coincided with high settlement so that no consistent pattern emerged. River discharge was lower than 100 m^3/sec during the settlement period in 1992-93 and 1994-95 which is a relatively small volume for the Derwent Estuary. Consequently, river discharge effects may have been of such small magnitude that they were not detected.

4.3.7 Effect of Temperature and Salinity on Settlement Variability

Temperature and salinity patterns at Kangaroo Bluff, Sandy Bay Point and Taroona are shown in Figs. 4.16a and 4.16b. Temperature fluctuated during sampling in a similar pattern at both Kangaroo Bluff and Sandy Bay Point. Temperature at Kangaroo Bluff ranged from 13.6°C to 20.6°C, mean

Table 4.25 Correlations (r) between daily settlement and river discharge at a reasonable lag of days. Periods of settlement where hatching was low were excluded. *, **, ***, **** : Correlation significant at $P < 0.05$, $P < 0.01$, $P < 0.001$, and $P < 0.0001$, respectively.

Physical factors	Day lag	4 Years pooled n = 143	1992-93 n = 42	1993-94 n = 22	2 Years (1994-95&1995-96) pooled; n = 79	1994-95 n = 41	1995-96 n = 38
River discharge	0	- 0.14	0.01	0.27	- 0.12	- 0.08	- 0.22
	1	- 0.19*	0.05	- 0.07	- 0.14	- 0.002	- 0.28
	2	- 0.19	0.07	- 0.04	- 0.17	0.002	- 0.34*
	3	- 0.24**	0.12	- 0.22	- 0.27*	- 0.01	- 0.49**
	4	- 0.28***	0.08	- 0.26	- 0.37***	- 0.14	- 0.59***
	5	- 0.31***	0.09	- 0.23	- 0.36**	0.04	- 0.65****
	6	- 0.31***	0.06	- 0.06	- 0.39***	- 0.08	- 0.66****
	7	- 0.27***	0.12	- 0.05	- 0.37***	0.14	- 0.69****

Table 4.26 Correlations (r) between weekly settlement and river discharge at a reasonable lag of weeks. Settlement periods where hatching was low were excluded. *, ** : Selection significant at $P < 0.05$, and $P < 0.01$, respectively. No data of river discharge at lag of 11 to 13 weeks were available.

Physical factor	Week lag	4 Years pooled n = 33	1992-93 n = 14	1993-94 n = 6	2 Years (1994-95&1995-96) pooled; n = 13	1994-95 n = 7	1995-96 n = 6
River discharge	0	- 0.12	- 0.14	0.37	- 0.43	- 0.40	- 0.65
	1	- 0.20	- 0.22	- 0.17	- 0.49	0.29	- 0.94**
	2	- 0.12	- 0.42	0.39	- 0.06	0.53	- 0.39
	3	- 0.03	- 0.22	- 0.21	0.13	0.51	- 0.03
	4	0.25	0.06	- 0.36	0.69**	0.67	0.75
	5	0.35*	0.29	- 0.04	0.37	0.26	0.71
	6	0.37*	0.44	- 0.11	0.09	0.23	- 0.11
	7	0.42**	0.14	0.03	0.17	0.42	- 0.23
	8	0.45**	0.23	0.19	0.26	0.65	- 0.74
	9	0.42**	0.39	0.57	0.20	0.47	- 0.07
	10	0.34*	0.52*	- 0.37	- 0.06	0.05	- 0.14

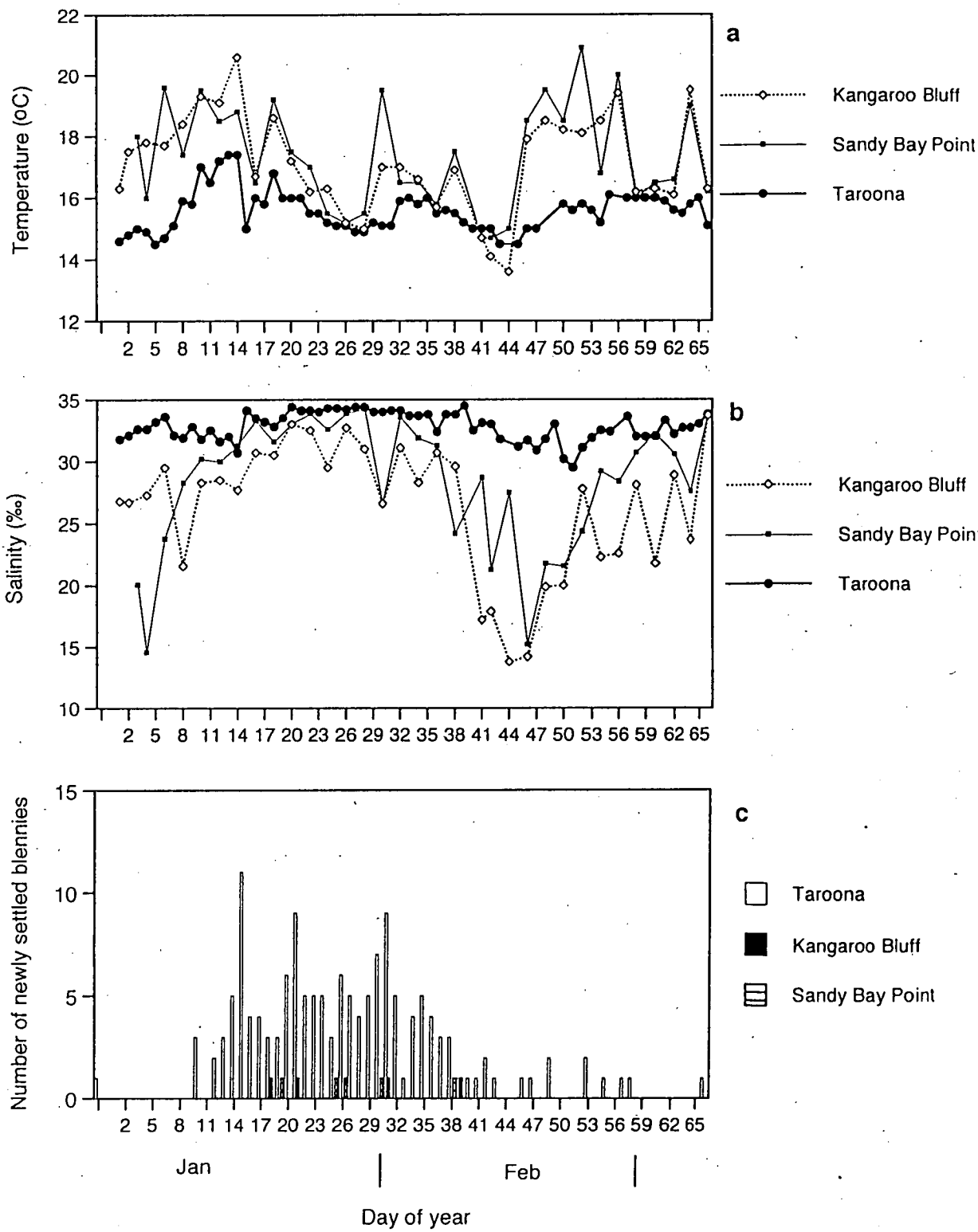

Figure 4.16. Temperature (a), salinity (b), and settlement (c) recorded during summer 1996 from three sites in the Derwent Estuary.

= 17.0 ± 1.59°C while at Sandy Bay Point it ranged from 14.7°C to 20.9°C, mean = 17.3 ± 1.66°C. The temperature at Taroona was generally lower than at Kangaroo Bluff and Sandy Bay Point but fluctuated in a similar pattern. Temperature at Taroona ranged from 14.5°C to 17.4°C with a mean of 15.5 ± 0.65°C.

Salinity varied between the three sites and dropped in mid February at both Sandy Bay Point and Taroona (Fig. 4.16b). Salinity at the most up-river site, Kangaroo Bluff, ranged from 13.8 to 33.7‰; mean = 26.7 ± 5.32‰ while at Sandy Bay Point, salinity ranged from 14.6 to 34.2‰; mean = 28.6 ± 5.29. Salinity at Taroona was generally higher than at either Kangaroo Bluff and Sandy Bay Point, ranging from 29.5 to 34.5‰; mean = 32.9 ± 1.11‰.

Settlement patterns at Kangaroo Bluff, Sandy Bay Point, and Taroona are shown in Fig. 4.16c. Site had a significant effect on settlement with highest settlement recorded at Taroona (149 newly settled blennies at Taroona, 4 newly settled blennies at Kangaroo Bluff, and 5 newly settled blennies at Sandy Bay Point, $P < 0.0001$).

No analysis could be conducted to assess the relationship between settlement and temperature and salinity at Kangaroo Bluff and Sandy Bay Point due to small sample sizes. To reduce sampling noise in data collected at the Taroona site, data were smoothed using 3 day moving-averages (Fig. 4.17). At Taroona, there appeared to be an effect of temperature on settlement at a lag of 1 to 7 d (Table 4.27, Figs. 4.18a-g) and salinity at a lag of 0 to 7 d (Table 4.27, Figs. 4.19a-h).

Since temperatures and salinities at Taroona were not measured at the surface, but at depth of 5 m, these data may not represent the water mass transporting pre-settlement larvae into tide pools. In attempt to assess the effect of surface water temperature and salinity on settlement, data from Sandy Bay Point were used in analyses. Data from this site were applied as it was geographically closest to Taroona and the temperature and salinity of water at Sandy Bay Point was significantly correlated to temperature and salinity at Taroona ($r = 0.48$, $P < 0.001$, $n = 53$ for temperature and $r = 0.66$, $P < 0.0001$, $n = 53$ for salinity). No correlation between temperature and number of newly settled blennies was found using water temperature data collected at Sandy Bay Point although significant correlation between salinity and settlement emerged at lags of 0 to 3 d ($P < 0.0001$ for all 4 days, Table 4.27, Fig. 4.20a-d).

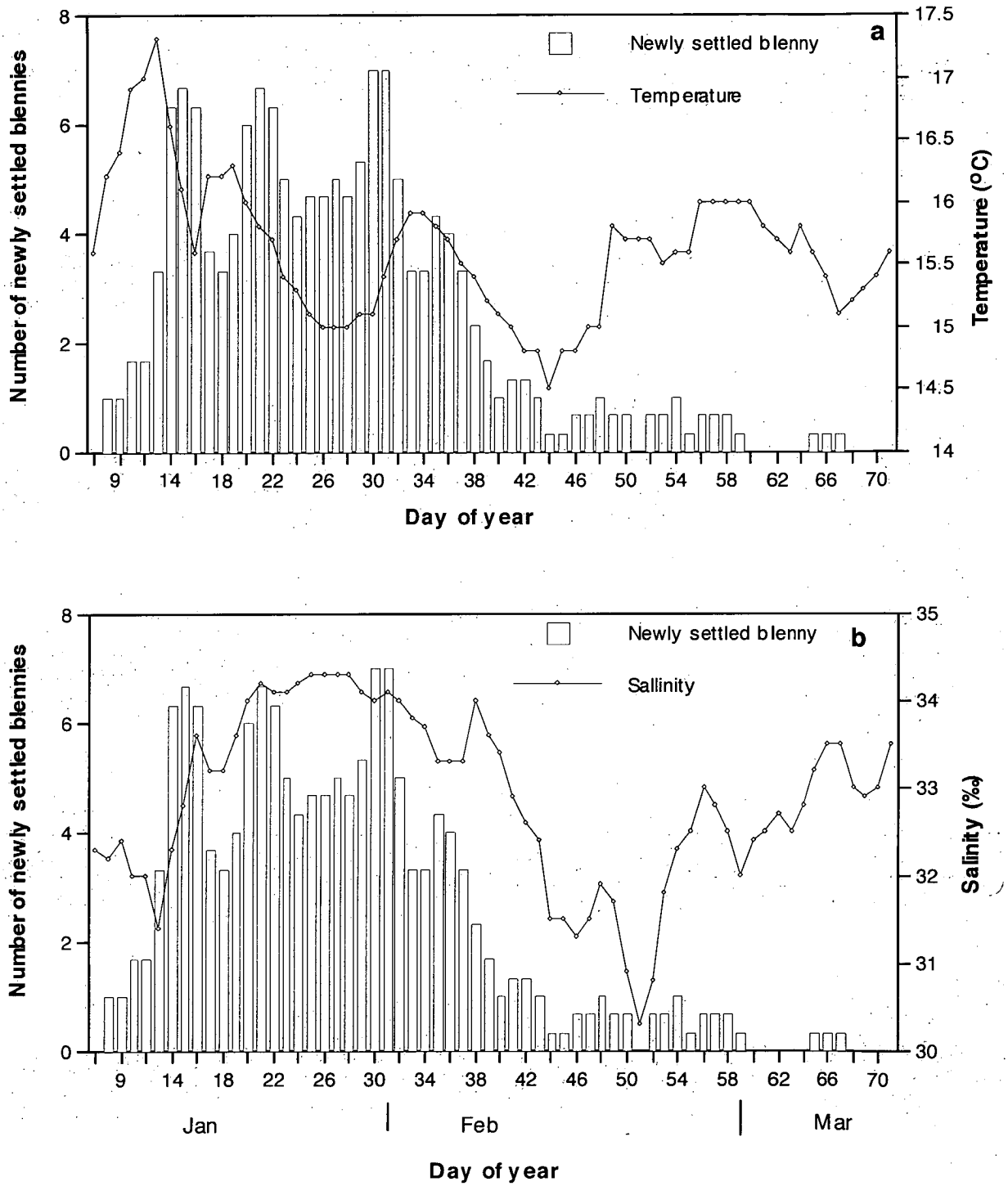

Figure 4.17. Pattern of temperature (a), salinity (b) and settlement at Taroona with data smoothed using 3 days moving average.

Table 4.27 Correlations (r) of settlement with temperature and salinity (recorded at Taroona during summer in 1996) at lags of up to 7 days. *, **, ***, ****: Selection significant at $P < 0.05$, $P < 0.01$, P , 0.001, $P < 0.0001$. 1: analysis based on all data points during sampling period, 2: analysis based on data where points before or after the main peak in settlement were excluded.

Site	lag day	1 (n = 50)		2 (n = 28)	
		Temperature	Salinity	Temperature	Salinity
Taroona	0	0.13	0.78****	- 0.46**	0.49**
	1	0.28*	0.69****	- 0.24	0.33
	2	0.35*	0.62****	- 0.05	0.22
	3	0.39**	0.60****	0.09	0.19
	4	0.36**	0.58****	- 0.07	0.24
	5	0.33*	0.54****	- 0.23	0.24
	6	0.32*	0.46***	- 0.24	0.18
	7	0.40**	0.35**	- 0.05	0.05
Sandy Bay Point	0	- 0.24	0.71****	- 0.15	0.37*
	1	- 0.16	0.73****	- 0.04	0.18
	2	- 0.11	0.77****	- 0.05	0.22
	3	- 0.06	0.79****	- 0.09	0.46**

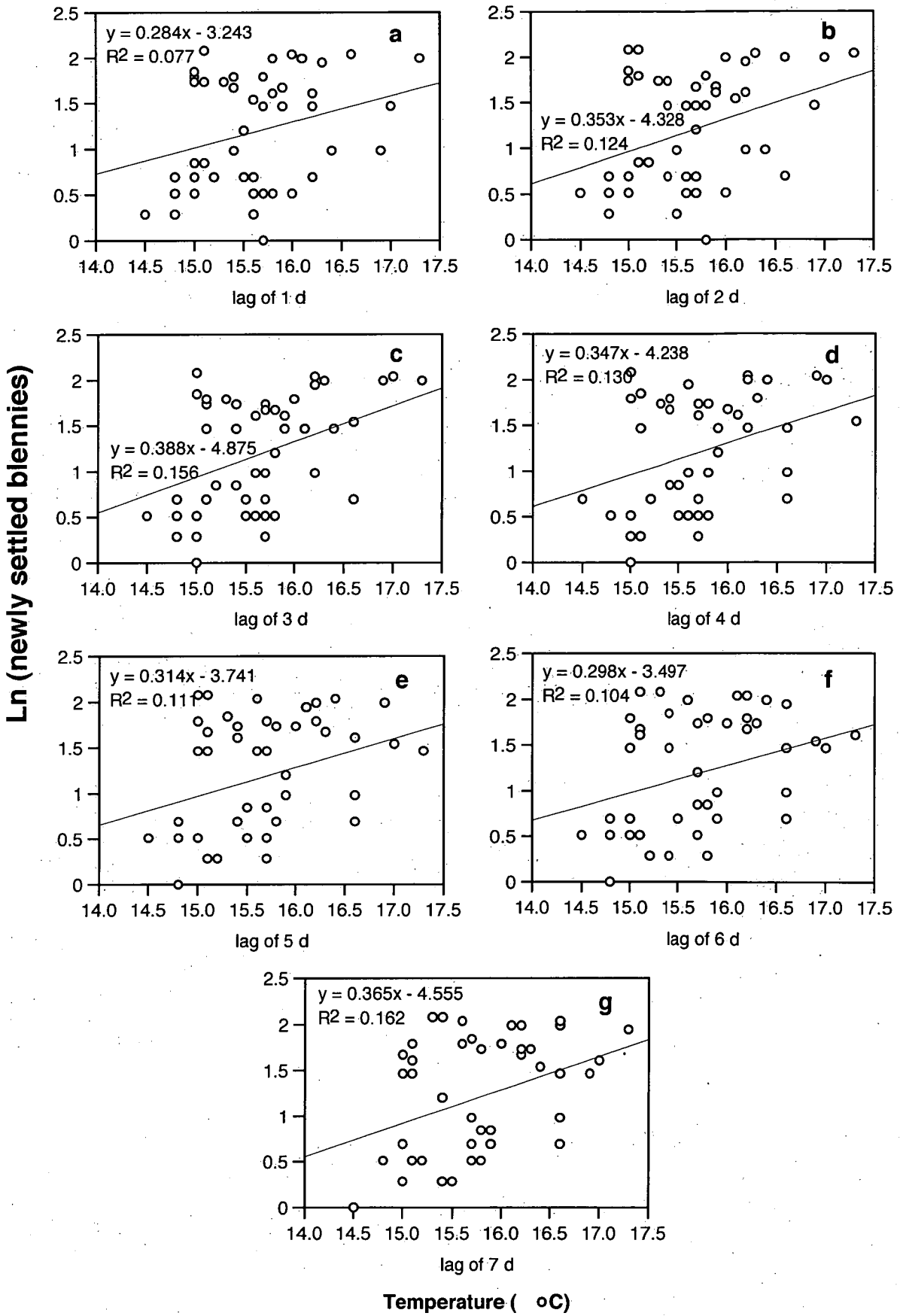

Figure 4.18. Regressions of ln newly settled blennies (3 days moving averages) against temperature (recorded at Taroona) at lags of 1 to 7 d (a-g). Analyses were based on data where points before or after the settlement peak were excluded.

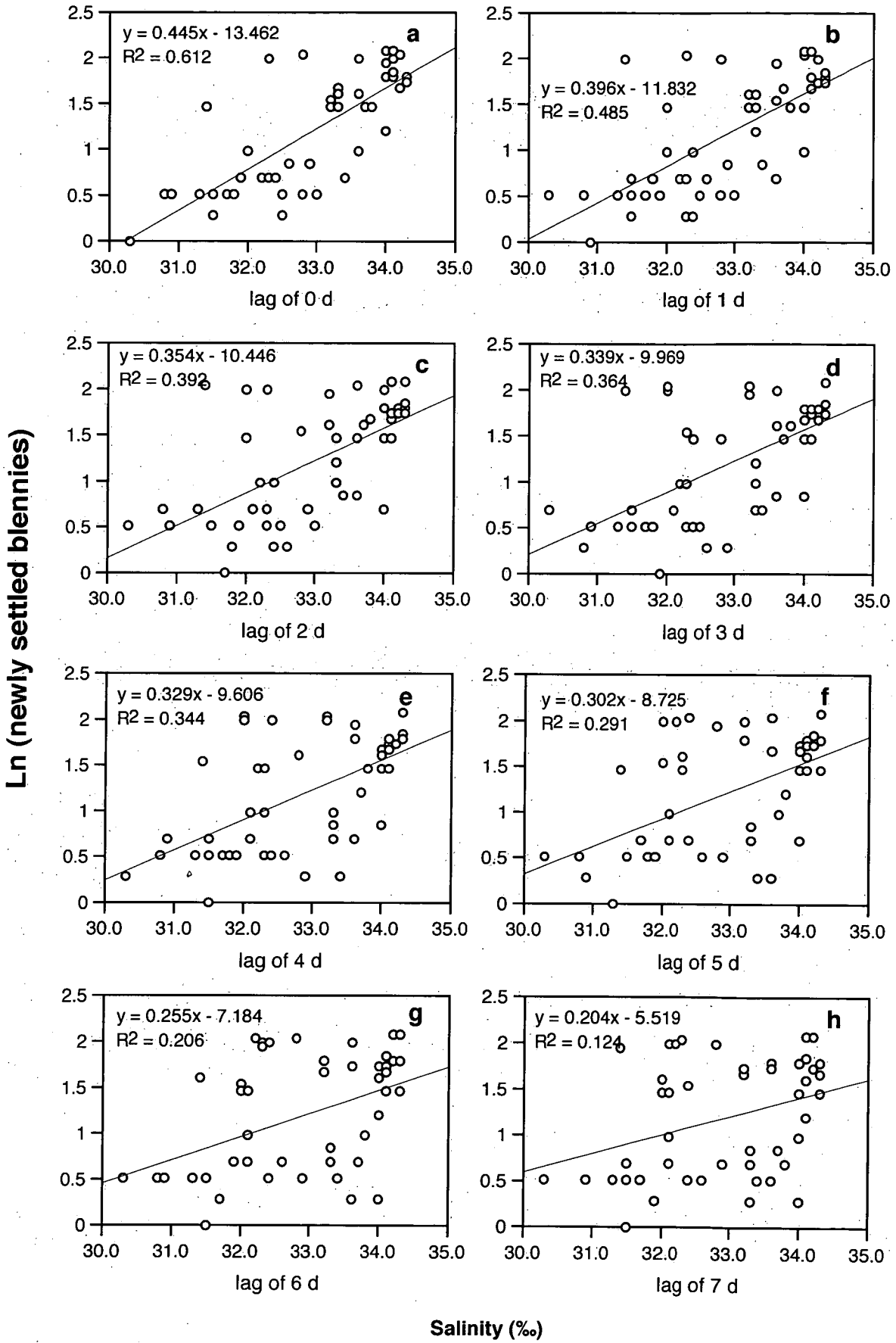

Figure 4.19. Regressions of ln newly settled blennies (3 days moving averages) against salinity (recorded at Taroona) at lags of 0 to 7 d (a-h). Based on data where points before or after the settlement peak were excluded.

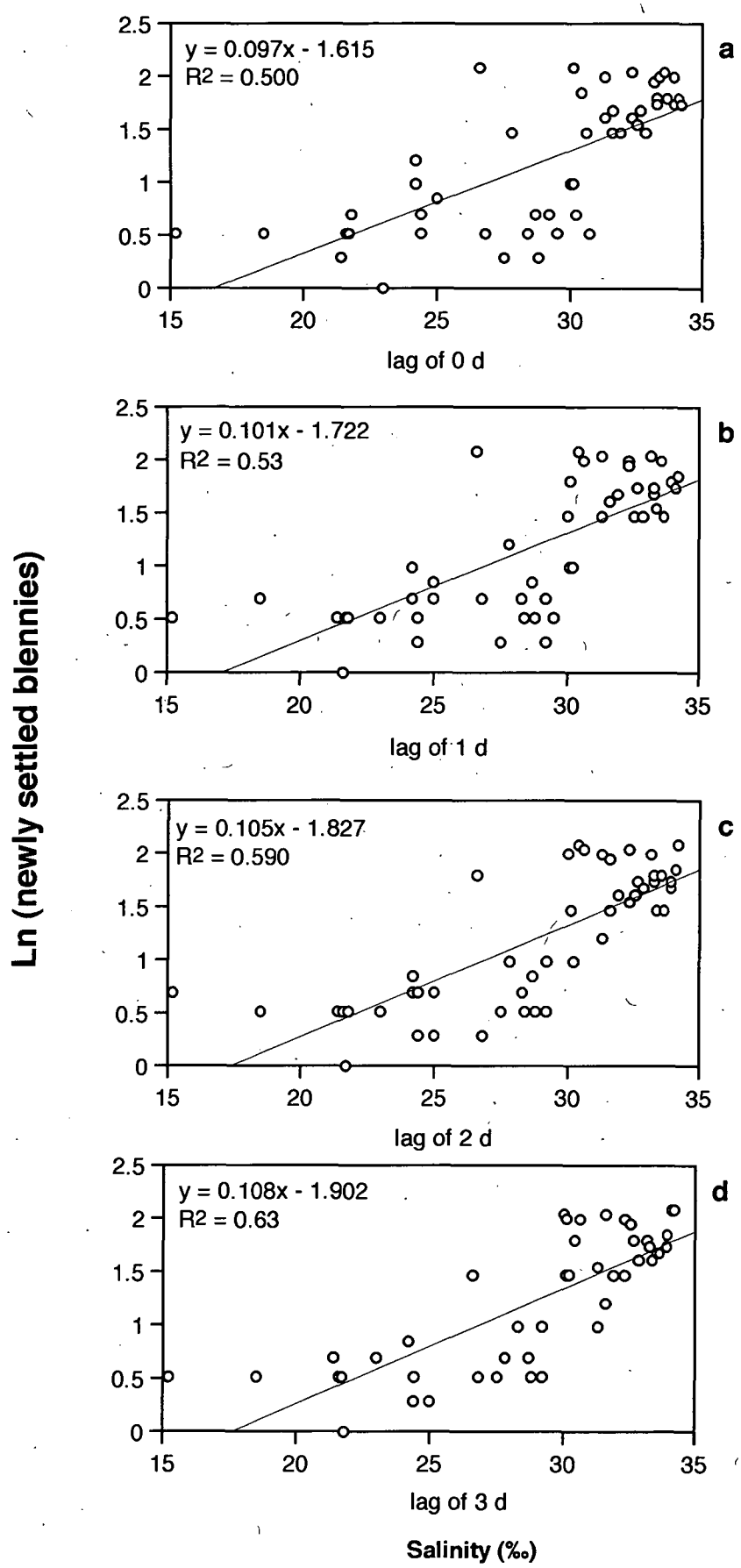

Figure 4.20. Regressions of ln newly settled blennies (3 days moving averages) against salinity (recorded at Sandy Bay Point) at lags of 0 to 3 d (a-d). Analyses were based on data where points before or after the settlement peak were excluded.

The apparent significant effect of temperature and salinity on settlement may have been due to simultaneous drop in salinity and temperature in March (autumn) when seasonal decline in settlement occurred, rather than an actual effect of these factors on settlement. To test this hypothesis, data collected before and after the main peak period of settlement (11 - 38 days) were excluded. Possible effects of low hatching were also considered, although no data were adjusted as possible effects fell outside the period of peak settlement. When only data from the period of peak settlement were considered, the effect of temperature at only lag of 0 d was significant ($P < 0.01$, Fig. 4.21a). Salinity at Taroona (lag of 0 d) appeared to strongly influence larval settlement ($P < 0.01$, Fig. 4.21b) and a weak correlation was observed with salinity at Sandy Bay Point (lag of 0 d) ($P = 0.05$, Fig. 4.21c). Significant correlation between newly settled blennies and salinity at Sandy Bay Point also emerged at a lag of 3 d ($P < 0.01$, Fig. 4.21d).

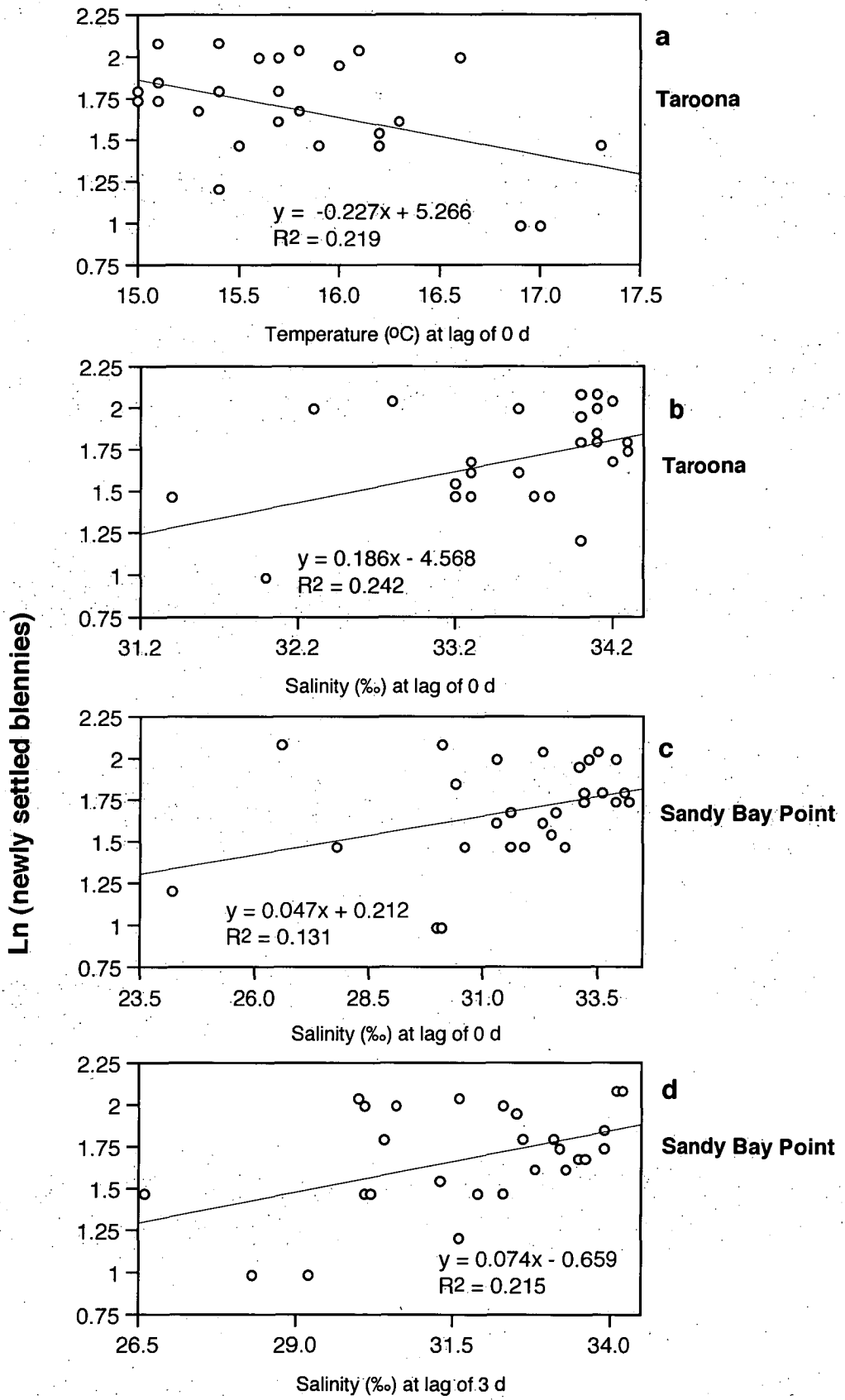

Figure 4.21. Regressions of ln newly settled blennies (3 days moving averages) against temperature recorded at Taroona at a lag of 0 d (a), against salinity recorded at Taroona at a lag of 0 d (b), against salinity recorded at Sandy Bay Point at a lag of 0 d (c), and 3 d (d). Analyses were based on settlement data where periods of low hatching were excluded.

4.4 DISCUSSION

Effect of Tidal Range and Lunar Phase on Hatching Dates and Settlement Variability

In the present study, no significant relationship was observed between hatching dates and lunar phase when data were pooled across 4 years ($P = 0.7$) and across 2 years of 1994-95 and 1995-96 ($P = 0.07$). When analyses were assessed in individual years, the significant effect of lunar phase on hatching dates emerged only in 1995-96 ($P < 0.001$). This suggests that hatching dates based on back-calculated settled juveniles of blennies did not exhibit lunar cycle due to lack of consistency. However the strong trend of greatest hatch occurred on the full moon in 1994-95 and 1995-96. This suggests that blennies may tend to hatch once per month which conforms with Thresher's suggestion (1984) that demersal-spawning fish tend to produce new clutches either every two weeks or monthly, usually on a lunar cycle. Larval survival may be enhanced by the observed pattern of hatching on the full moon as newly hatched larvae are likely to be phototaxic. Under natural conditions, movement toward light of newly hatched larvae would result in movement toward the surface, increasing dispersal away from the rocky reef (Leis, 1991a).

The observed strong trend of high settlement during the waxing/waning half moon is similar to the results of Thorrold et al. (1994b), who reported semi-lunar cycling in settlement of scarids and ophichthids and lunar cycling in gobiids, bothids and apogonids. Sponaugle and Cowen (1994) reported that settlement of Caribbean gobies, *Coryphopterus glaucofraenum* and *Gnatholepis thompsoni* occurred predominantly around the third quarter moon. Labelle and Nursall (1992) reported that a blenniid *Ophioblennus atlanticus* recruits to coastal reefs of Barbados during the new moon. The settlement in blennies around waning half moons was significant only when data were pooled across 4 years ($P = 0.02$, analyses were based on data where periods of low hatching were excluded), no significant effect of lunar phase emerged when data were pooled across 2 years of 1994-95 and 1995-96 ($P = 0.4$) and also settlement did not show evident periodicity in lunar phase for any year. These findings in other demersal reef species support the suggestion that lunar phase may affect blenny settlement, but was not detected statistically due to lack of power.

The "settlement-linkage" hypothesis of Christy (1978) and Kingsford (1980) focuses on the end of the larval life and proposes that temporal patterns of larval production represent adaptations to maximize settlement of juveniles. This hypothesis suggest that If larvae have relatively fixed development periods (relatively fixed-age settlers), and there are preferred lunar phases for settlement, then there will be selection for time of the release of larvae so that most will be competent to settle at the preferred times. Conversely, lunar spawning cycles may be absent in species that have variable-age settlers or lack preferred settlement periods. The present study supported this hypothesis to some extent; blennies appear to be variable age settlers (36 - 69 days, see Chapter 3, Section 3.3.6) and, although it was not significant, they showed a strong trend to hatch on the full moon yet no consistent significant effect of lunar phase on settlement patterns was observed ($P > 0.05$). However, although the trend of high settlement during the waning half moon period (first quarter) and low settlement during full moon period in 1994-95 and 1995-96 was not significant ($P > 0.05$), it does suggest that there may be an underlying settlement mechanism associated with the lunar phase. A similar pattern of low settlement during the full moon period has been observed in other reef fish and is assumed to be an adaptation to reduce predation on settling reef fishes (Sweatman, 1988). This lunar settling pattern is believed to be augmented in some species by olfactory cues which are employed to choose among sites during nocturnal settlement (Sweatman, 1988). If blennies also utilise olfactory cues then results may have been confounded to some extent so that patterns were less clear. The trend of low settlement during full moons may be related to predation as recruits tend to suffer higher rates of predation on full moons than during other lunar phases (Hobson et al., 1981).

Victor (1986) suggested that if settlement follows lunar patterns, tidal movement may also play a role in promoting settlement. A proposed mechanism for this is that if larvae rely on tidal currents to move them inshore, greater tidal fluxes (during spring tides) would result in greater inshore migration (Victor, 1986). In the present study, the hatching dates and settlement of blennies did not appear to be influenced by tidal currents. This is in contrast to discussions by Thorrold et al. (1994b), who reported that most settlement-stage fishes moved onshore during flood tides. There are exceptions to this general pattern, for instance, McFarland et al. (1985) reported that the phase of settlement of Young French Grunts, *Haemulon flavolineatum*, was associated with intermediate tide level. However, even in the case of *H. flavolineatum* settlement was affected by

tidal movement; the apparent absence of tidal effects on blennies is surprising.

In conclusion, it appears that the hatching of blennies did not follow lunar cycles and there may be settlement associated with the lunar phase. Tidal fluctuations did not affect hatching or settlement.

Effect of Wind on Hatching Dates and Settlement Variability

In the present study, there appeared to be no effect of wind strength on hatching dates and settlement. This is in contrast to observations of Thresher (pers. comm.) who found settlement of benthic reef fish (clinids *Heteroclinus* spp.) was related to wind at South Arm, (a site in the Derwent River Estuary opposite to the Taroona sampling site in the present study). He suggested that wind may be critical in determining patterns of spatial concordance over short time scales. In this study, there was no effect of wind on the settlement pattern of blennies which is unexpected. Many studies show the effect of wind on settlement of benthic fish and invertebrates. For examples, Jones and Epifanio (1995) showed that a strong association exits between the settlement of the Portunid crab, *Callinectes sapidus* and southward wind events in Delaware Bay, Cape Henlopen. Thorrold et al. (1994b) reported significant relationships between wind and larval supply of summer-recruiting reef fishes to Lee Stocking Island, Bahamas. The major sampling site in this study (Taroona) is on the southwestern of the Derwent Estuary and is fully exposed to south-easterly wind. Consequently, it was hypothesized that south-easterly wind should drive settling blenny larvae into tide pools. The observed result were not consistent with this expectation as wind did not appear to affect settlement. Wind tends to affect water mass stability which in turn can affect settlement of marine organisms. The absence of wind effects on settlement and hatching of blennies may have resulted from characteristics of the exchange of water masses in and out of the Derwent River Estuary which is relatively slow (Clementson et al., 1989). Consequently, the large scale episodic flushing of the Derwent River Estuary that would be required to cause marked variability in settlement is unlikely to occur.

Effect of River Discharge and Rainfall on Hatching Dates and Settlement Variability

Results of the present investigation showed that there was no consistent effect of river discharge and rainfall on hatching dates and settlement when analysed over both daily and weekly periods at any reasonable lags. River flows tend to affect estuarine fish as reported by Turner and Chadwick (1972) who found that a significant positive correlation exists between river flows in the Sacramento-SanJoaquin Estuary and year-class strength of striped bass, *Morone saxatilis*. Hayman and Tyler (1980) also found a significant correlation (inverse) between Columbia River flows and year-class strength of Dove sole, *Microstomus pacificus* and Crecco and Savoy (1984) reported that year-class strength of American shad (*Alosa sapidissima*) in the Connecticut River was inversely related to river flows and total precipitation. They suggested that high river flows and low river temperatures reduce larval feeding success, survival, and ultimately shad year class strength. Given that river flow and rainfall tend to affect estuarine fish recruitment, it is surprising that no patterns were seen with blennies in the Derwent Estuary. This is especially intriguing as salinity was shown to affect settlement. The Derwent River Estuary is a very deep estuary, reaching over 50 m depth in places and salinity may be strongly affected by current movement (Nyan Taw, 1975). This may confound effects of river flow and rainfall on blenny settlement so that no effect was detected.

Effect of Temperature and Salinity on Settlement Variability

The intensive settlement sampling showed that highest settlement occurred at Taroona when the water salinity was highest while low or almost no settlement was found at Kangaroo Bluff and Sandy Bay Point when water salinity was lower. Settlement at Taroona was significantly related to water salinity but was not related to water temperature. This suggests that the salinity preferences of newly settled blennies differed from larvae sampled in plankton tows (see Chapter 5).

The difference in settlement between sites may result from the preference of newly settled blennies for high salinity water, which may provide more prey items in the Derwent Estuary. The marine zone of the Derwent River Estuary extends upriver as far as Cornelian Bay (Fig. 4.1) (Guiler, 1955). Nyan Taw (1975) showed that though Storm Bay was normally inshore-coastal and coastal in nature, it was occasionally influenced by both

estuarine and oceanic water with an oceanic water influence for some considerable distance up the river along the west bank. Wood (1954) found some evidence that the Subtropical Convergence may move as far as Storm Bay as shown by the presence of subantarctic planktonic dinoflagellates. Nyan Taw's findings (unpublished data cited by Nyan Taw and Ritz, 1979) supported Wood's findings as he demonstrated that the inshore region of the east coast of Tasmania, about 35 km to the east of mouth of the Derwent River and Storm Bay areas, was influenced by subantarctic water in October, November and December. Subantarctic water is cool and rich in nutrients. These findings suggest that this water mass may bring food such as planktonic dinoflagellates and nutrients to the area where high settlement occurred.

A few old larvae were found near the Kangaroo Bluff site where salinity was low, yet low settlement occurred at this area. At Taroona, salinity was relatively high and there appeared to be few pre-settlement larvae; despite this, relatively high settlement was recorded. There may have been some degree of error in interpreting the water characteristics from the Taroona site as samples were taken from water drawn from depth of 5 m while blennies settle near the surface. Nonetheless, the results are intriguing and four hypotheses are suggested to explain this discrepancy between salinity preferences of planktonic larvae and settled juveniles.

First, tide pools at Taroona appear to be more structurally complex. Aside from personal observations on shelter variation between sites, H. B. Wommersley (pers. comm.) has noted macroalgae assemblages in the upper subtidal at Taroona which are relatively unique in the Hobart region. This differing availability of shelter may in turn reduce predation. For example, predation efficiency of piscivorous predators has been shown to decrease with increasing habitat complexity (Mattila, 1992). Spatial variation in demersal fish recruitment is often perceived as habitat selection, particularly when recruitment to a specific habitat is disproportionately high relative to the abundance of that habitat (Carr, 1991) and some fish species may actively select specific microhabitats at settlement (Sale et al., 1984). Recruitment variation among habitats may also result from agonistic and antagonistic interactions with conspecific or competitors (Sweatman, 1985; 1988) which can in turn be affected by shelter availability.

Secondly, Kangaroo Bluff and Sandy Bay Point are relatively disturbed and polluted areas which may have affected settlement of blennies.

Domestic sewage discharge was often observed to be contaminating pools. Studies of heavy metal concentration in the Derwent Estuary (Langlois et al., 1987) have shown that sites on the west bank, such as Taroona , tend to be far cleaner than sites on the bank (e.g. Kangaroo Bluff) or those towards the Tasman Bridge (e.g. Sandy Bay Point).

Thirdly, tide pools at Kangaroo Bluff and Sandy Bay Point were slightly more elevated than those at Taroona so that they were flushed less frequently by the tide. Tidal flushing is clearly necessary if blennies are to recruit to the pools.

Fourth, the observed settlement rates could also be a product of different predator densities. Carr and Hixon (1995) reported predation effects on early post-settlement survivorship of coral-reef fish *Chromis cyanea* (Pomacentridae), and *Halichoeres pictus* (Labridae) in living coral near Lee Stocking Island, Bahamas. They found that the survivorship of these two new recruits on predator-free reefs was significantly greater than on the predator present (control) reefs. They concluded that resident predators can substantially alter the local density and size structure of reef fishes shortly after they settle from the plankton. The high mortality rates typically associated with post-settlement juveniles are thought to be primarily due to predation (Houde 1987). Crabs are considered an important taxa for predation on settling benthic fish species (Pihl, 1990) and wide variation in the density and assemblages of shore crabs (Grapsidae) has been noted along the Derwent Estuary (Griffin, 1971).

In the present study, water temperature did not significantly correlate to settlement yet there appeared to be a strong trend of high settlement when temperature was higher. Temperature may influence larval growth and survival, hence magnitude in settlement. Mills (1994) reported that the optimal larval rearing temperature of the Tasmanian blenny is 21°C while larvae reared at the optimum incubation temperature (15°C and 18°C) had very poor growth and survival. He suggested that if these results are extrapolated to the wild, very few blenny larvae would survive at low water temperatures. These optimal incubation temperatures (as opposed to rearing) are equivalent to those that larvae would be exposed to in nature (mean temperature ranged from 15.5°C to 17.3°C). Consequently, the observed trend of higher settlement with higher temperature may reflect actual poorer survival at lower temperatures.

Some biological and physical factors which were not examined in this study but which may influence settlement include photoperiod, prey density, predators, fecundity, gonadosomatic index (GSI), post-settlement mortality and habitat selection. Richards and Lindeman (1987) suggested that recruitment to a fishery is a function of parent fecundity which can be highly variable. They also suggested that biotic and abiotic factors influencing annual fecundity can influence year class abundances as greatly as events affecting the planktonic larvae. Cook (1986) calculated the fecundity of *P. t. tasmanianus* to be 25,000-30,000 eggs annually which is high relative to the size of the adult. He found that reproductive output was reduced on low food rations by both reduction in batch sizes and by fewer spawnings. Periods of poor settlement of blennies in the present study may be due to periods of low fecundity resulting from low rations.

Back-calculated hatch dates in this study are derived from settlement dates data which are those of the survivors. There was no independent measure of true spawning intensity to examine patterns in recruitment that are physical driven, independent of spawning intensity. A large settlement may have been produced by a potent but small spawning under ideal physical conditions and vice versa. Therefore it would be much better not to base the hatched dates on settlement dates only but also collect GSI data to confirm the hatching dates and number of newly hatched competent larvae and hence subsequent settlements. Cook (1986) stated that ripe ovaries and testes of blennies began to appear in September, indicating a spring spawning period which is in agreement with time of hatching dates examined in this study. Cook (1986) did not present the information on the duration of the spawning period due to time limitations but from his experimental evidence and from studies of other blennies (Qasim, 1957; Milton, 1983 cited by Cook, 1986) he suggested that an extended spring/summer spawning period of 3-4 months is predicted, characterized by multiple intermittent spawning which is consistent with a period of hatching in this study. Due to logistical and financial constraints GSI data were not collected in this study.

Photoperiod is among the factors affecting settlement which were not assessed and is generally believed to play an important role in spawning, and thus hatching and settlement of fish in estuaries. Hatching of several temperate demersal spawning fish appear to be influenced by photoperiod (Doherty, 1983; Alcalay and Sikkel, 1994).

In summary, the present study indicated that hatching dates and settlement of the Tasmanian blennies were not strongly influenced by most of the physical factors assessed. Lunar phase appeared to have no effect on settlement while salinity and temperature appeared to influence settlement, although these relationships were not strong. Further study may identify other factors, as mentioned above, which may influence hatching and the settlement.

The Taroona site clearly offers more suitable settlement habitat than the two other sites sampled (based on the presence of large numbers of newly settled juveniles). However, it is not yet known what physical factors drive the pre-settlement larvae to recruit to the tide pool. It is important to note that pre-settlement larvae were never found in plankton samples collected from Taroona so the location and possible migration of larvae recruiting to this site remains unclear. Further study is required to establish the source of the pre-settlement larvae to assist in understanding factors affecting recruitment.

In summary the main findings of this study were:

- Tidal cycle, rainfall, and river discharge appeared to have little effect on hatching and settlement variability.
- Lunar cycle appeared to influence hatching and settlement (greatest number on waning half moon).
- Wind did not appear to affect settlement when assessed for either daily or weekly lags.
- There was a strong trend of high settlement when temperature was high.
- Salinity is a useful predictor of the abundance and distribution of settlement which newly settled juveniles preferred higher salinity.

CHAPTER 5

EFFECT OF PHYSICAL FACTORS ON THE ABUNDANCE OF TASMANIAN BLENNY LARVAE

5.1 INTRODUCTION

Day (1980) defined an "estuary" as "a partially enclosed body of water which is either permanently or periodically open to the sea and within which there is a measurable variation of salinity due to the mixture of sea water with fresh water derived from land drainage". Most Australian estuaries are partially mixed normal estuaries which have a layer of freshwater flowing out on the surface and a denser saline layer flowing in along the bottom (Newell and Barber, 1975; Day, 1981a), with salinity increasing further from the mouth of the river. This type of estuary is indicative of drowned river valleys such as the Derwent River Estuary (Davies and Kalish, 1994). They are highly variable environments, defined and strongly influenced by the coastal ocean and upland freshwater drainages that border them.

An important trophic component of estuarine communities are fish and their larvae. It is widely believed that estuarine nurseries offer young fish, including marine species, a measure of protection from predators and a plentiful food supply (Boesch and Turner 1984). Year class strength of these species is strongly influenced by survival through the larval period as mortality rates of larvae can be as high as 99% (Lieby, 1984). The survival, distribution and recruitment of larvae in estuaries are directly related to the hydrological, biological, and behavioural factors; understanding these relationships may allow fluctuations in year class strength to be understood (Fortier and Leggett, 1982; Norcoss and Shaw, 1984; Kingsford, 1990).

These mechanisms controlling distribution, abundance, growth and survival of early life history stages are generally difficult to identify in estuaries because the dominant process may vary between sites and change over time. For example, food limitation and predation may be the primary causes of mortality in fish larvae, but the effects of these factors, alone or in combination, can be modified by temperature (Frank and

Leggett, 1982), river flows (Crecco and Savoy, 1987; Savoy and Crecco, 1988), small-scale turbulence caused by winds and tide (MacKenzie and Leggett, 1991), or a variety of other factors that vary widely within estuaries.

An important component of the variability of estuarine nursery areas is the changes in temperatures and salinities which is clearly far greater than either freshwater or marine habitats (Stickney, 1959). In turn, temperature and salinity influence estuarine currents, both of which are mainly determined by the ratio of river to tidal flow with circular motions induced by coriolis force (Day, 1981a). Depth can compound the effect of temperature as the diurnal changes in temperature are relatively greater in shallow estuaries (McHugh, 1967). Likewise, seasonal patterns are also important; in the summer the surface waters are generally warmer than the deeper waters, while in winter the deeper waters tend to be warmer. Seasonal changes in the horizontal gradient occur with a seaward increase in temperature in summer and the reverse in winter (Day, 1981b).

Temperature is often considered the most important factor influencing the growth and survival of larvae (Lieby, 1984; Allen and Barker, 1990). As Tasmania has a temperate climate, seasonal temperature fluctuations can be expected to be important in larval fish survival. This has been demonstrated by indirect evidence of Harris et al. (1988) who showed that mean number of trout was correlated with mean maximum air temperature. This resulted from larval survival of trout relating to rainfall and stream flow. The interannual and spatial variation in growth rate of blue grenadier larvae *Macruronus novaezelandiae* collected from the south, east coast and the west coast of Tasmanian water is likely related to water temperature (Thresher et al., 1988).

Seasonal changes in salinity reflects rainfall patterns so that in periods of drought, when there is little freshwater input and evaporation is intense, salinity tends to be greater upstream (Newell and Barber, 1975; Day, 1981b; Gaughan et al., 1990). Conversely in the rainy season, estuarine waters become more diluted and brackish water can extend far out to sea (Newell and Barber, 1975). In response to these changes of salinity, estuarine organisms tend to be distributed along salinity gradients. For example, Longeragan and Potter (1990) found that species composition reflected seasonal changes in salinity and distance from the mouth of the estuary. Thus salinity variations tend to play an important role for estuarine and nearshore larvae.

Ecosystems are complex environments and cannot be fully explained by simply assessing the role of physical factors (Gagné and Fortier, 1989; Fortier and Gagné, 1990). Consequently, many authors stress the importance of understanding the interaction of biotic and abiotic constraints on larvae.

In the chapter 3, it was shown that the abundance of larval blennies does not appear to be related to pulses in phytoplankton production. In this chapter, an alternative hypothesis, that the abundance of blenny larvae is determined by physical factors, was examined by seeking correlations between larval abundance and river discharge, rainfall, wind, tidal range, lunar phase, surface water temperature, and salinity.

The growth rate of larvae may affect their survival and hence be one of the factors governing recruitment variability (Shepherd and Cushing, 1980; Rice et al., 1993). Regardless of the original source of the larvae or the mechanism by which successive cohorts are introduced to estuarine nurseries, the environment experienced by each cohort is likely to be different so growth and survival will vary among cohorts using the same nursery (e.g. Gamble et al., 1985; Leak and Houde, 1987; McBride and Conover, 1991; Kneib, 1993). Consequently, growth rates of blenny larvae were also investigated in this study using otolith microstructure analysis to allow the estimation of population growth curves from length-at-age data (Maillet and Checkley, 1991).

5.2 MATERIALS AND METHODS

5.2.1 Sampling Sites

Sampling was conducted at a single station in the Derwent Estuary as described in Chapter 2, section 2.2.

5.2.2 Field Sampling

5.2.2.1 Larval Fish Sampling

Sampling of fish larvae was conducted by the same method as described in Chapter 2, section 2.3.1.

5.2.2.2 Physical Factors Measurement

5.2.2.2.1 Temperature and Salinity

Salinity and temperature were measured weekly with a Platypus™ submersible data logger (SDL) at a depth between 0 and 1 m.

5.2.2.2.2 Tide

Tidal data for the Port of Hobart was obtained from tables compiled by the Tidal Laboratory of the Flinders University of South Australia (1992, 1993, 1994). Tide was assigned to either flood or ebb tide for analysis.

5.2.2.2.3 Lunar Phase

Lunar periodicity data in 1992, 1993, and 1994 were obtained from astronomical data supplied by Australian Surveying and Land Information Group. For the purpose of analysis, the lunar cycle was split into 4 groups. These groups were formed using calendar days so that each lunar phase fell in the middle of each group.

5.2.2.2.4 Wind Pattern

Hourly wind data were recorded at Battery Point by the Bureau of Meteorology (Fig. 4.1, chapter 4). While these records are not a perfect measure of conditions at the sampling sites, they broadly reflect the daily, weekly, seasonal and interannual variability in the local weather. Due to the form of the estuary, south-easterly winds tend to cause the greatest wave action at Taroona where larval samples were collected. Consequently, the south-easterly component of the wind was calculated from wind velocity and wind direction by the formula:

SE = (*S*) cos (Degree to Radius (Ø - 110º)

where SE was the south-easterly component, *S* was the wind speed recorded in knots, and Ø was the wind direction in degrees from true north. The Taroona sampling site was approximately 110º true north of Storm Bay. The equation transformed the entire wind field into approximately north-westward and south-eastward wind vectors. Wind speed data were collected as averages over eight hour periods; the mean daily value and the maximum daily value was then used in analysis of abundance of larvae.

5.2.2.2.5 Rainfall

Daily rainfall (mm) data were recorded at the Taroona sampling site by the Bureau of Meteorology, Hobart.

5.2.2.2.6 River Discharge

Mean daily Derwent River discharge (m^3/s) was recorded at Meadow Bank (Chapter 4, Fig. 4.1) by the Tasmanian Hydro-Electric Commission for the periods 1992-93 and 1993-94 during spring/summer.

5.2.2.3 Intensive Larval Fish Sampling in Different Water Mass

In 1992-93 and 1993-94, peaks of larval abundance tended to correspond to periods of high temperature and low salinity (Fig. 5.9). The hypothesis that water masses with high temperature and low salinity affect the abundance of the larvae was tested by intensive larval fish sampling in 1996. This intensive sampling involved daily collection of larvae undertaken during summer from 4 sites where water mass characterised by salinity and temperature varied.

5.2.2.3.1 Sampling Sites for Intensive Larval Fish Sampling

The sampling sites for intensive larval fish sampling were nearshore stations within the Derwent Estuary. Sites were chosen on the basis of differing salinity. The four sites selected were: Taroona, Sandy Bay Point, Tranmere, and Kangaroo Bluff (Fig. 5.1).

5.2.2.3.2 Temperature and Salinity Measurement for Intensive Sampling

The temperature and salinity of surface water (0-1 m deep) were measured with a WTW™ microprocessor conductivity meter (LF 196) to distinguish water masses before sampling fish larvae.

5.2.2.3.3 Intensive Larval Fish Sampling

Larval fish sampling was conducted from a 5 m launch (FRV Ophelia) on 8th January 1996 using a 500 μm mesh plankton net with a 100 cm mouth diameter. The net was towed for 10 minutes at 2 to 3 knots at approximately 50 cm depth. Towing was conducted close to shore (~10m) and also at 100 m offshore with 2 replicate tows at each location. Samples were then preserved in 95% ethanol. The results of this sampling exercise should be viewed with great caution as the sampling was undertaken only on one occasion.

5.2.3 Laboratory Analysis

5.2.3.1 Larval Fish Processing

After sorting, the number of larvae was converted to a standard measure of number of larvae per 250 m^3 sea water volume. Standard length (SL) was measured to the nearest 0.1 mm as described in Chapter 2, section 2.4.1.

5.2.3.2 Otolith Analysis

Daily growth increments of otoliths were counted and then growth curves, as length-at-otolithic age, were fitted. Otolith analysis is described in greater detail in chapter 2, section 2.4.2.

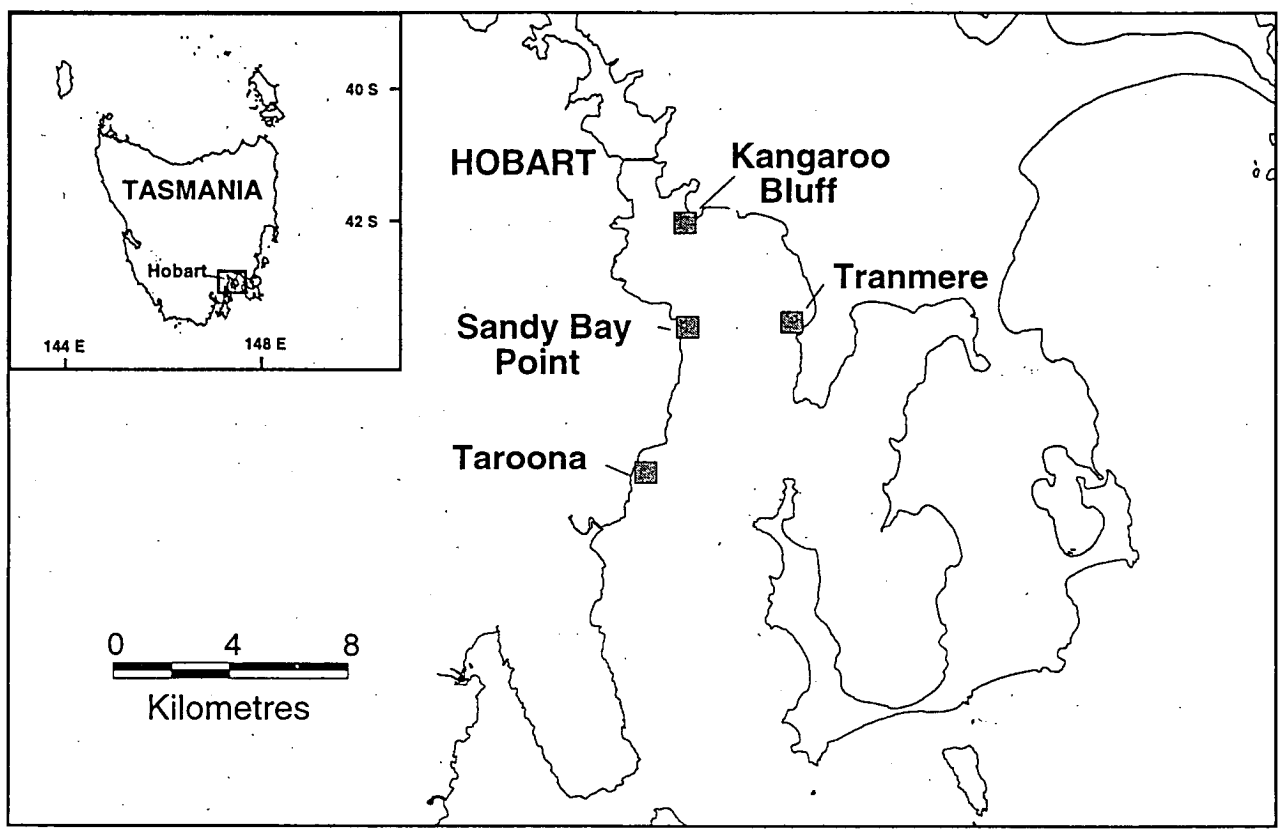

Figure 5.1 Sampling sites for intensive larval fish sampling. Solid rectangles indicate sites.

5.2.4 Statistical Analysis

The relationship between environmental factors and the abundance of larvae was assessed with account of lag effects over daily (0 to 5 d) and weekly intervals (0 to 3 w) (see chapter 2, section 2.5). Data were initially analysed in two forms to attempt to expose patterns: pooled for all years; and by separate years. Lunar phase appeared to influence hatching of blennies (chapter 4) so it was hypothesized that this may obscure patterns of effects of physical factors on larval abundance. Consequently, additional analyses were conducted to remove the effect of lunar cycles by analysing for partial correlation of blenny abundance with physical factors.

Stepwise, multiple regression (using the statistical package JMP 3.1) was used to find possible effects, however due to the large number of analyses undertaken, results were accepted with caution as numerous spurious relationships were indicated (Sokal, 1981). Consequently, relationships were only accepted as legitimate where the pattern was consistent over several years. The relationship between environmental factors which appeared to minimize error in the model was then assessed by classical linear regression (Myers, 1990). Prior to analysis, response variables were third root (x + 0.01) transformed to produce normality and to remove heterogeneity of variance.

5.2.4.1 Growth Rate Assessment

Growth curves (length-at-otolithic-age) of larvae from each year and from each site were fitted separately with simple linear regression. Analysis of covariance was used to compare growth rates between larvae in 1992-93 and 1993-94 and to compare growth rates between larvae collected from different sites for intensive larval fish sampling (Zar, 1984).

The average growth rate (mm/d) was computed for each larva by:

$$\text{Average growth rate} = (SL - 3.5) / \text{Age}$$

where SL = size (mm) at capture; 3.5 = average standard length (mm) at hatching which was estimated from size of wild caught back-calculated newly hatched larvae; and age = days post-hatching (estimated from increment counts on otolith).

The relationship between growth rate and water temperature was also investigated by linear regression of growth rate and temperature.

5.3 RESULTS

5.3.1 Abundance of Larvae

Larval abundance was described in chapter 3, section 3.3.3. In brief, a total of 46 larvae were caught during sampling in 1992-93, whereas 206 larvae were caught during sampling in 1993-94. The adjusted total number of blenny larvae per 250 m^3 of water filtered caught in 1992-93 was 0.52 larvae per sample, as compared with 3.39 larvae per sample for 1993-94. The difference in larval density between years is highly significant ($P < 0.0001$).

The pattern of temporal variation in larval abundance, by calendar week, is shown in Fig. 5.2. There appeared to be no significant difference in the number of larvae collected by surface (mean = 3.0 ± 6.7 larvae/250 m^3) or subsurface tows (mean = 1.6 ± 2.4 larvae/250 m^3) when data were pooled for 2 years ($P > 0.05$). However, there did appear to be an effect of depth when data were analysed for the 1992-93 season, as significantly fewer larvae were caught by surface tows (mean = 0.30 ± 0.50 larvae/250 m^3) than by subsurface tows (mean = 1.38 ± 1.44 larvae/250 m^3) ($P < 0.001$). There was also a strong effect of season on catch rates (differences between weeks, $P < 0.0001$), but no interaction was found between week and tow depth ($P > 0.05$). Overall, seasonal patterns of larval abundance as measured by either surface or subsurface tows were similar.

In 1993-94, the number of larvae caught by surface (mean = 3.03 ± 2.86 larvae/250 m^3) and subsurface tows (mean = 4.74 ± 9.33 larvae/250 m^3) did not differ significantly ($P > 0.05$), nor was there a significant interaction between week and tow type ($P > 0.05$). However, there was a conspicuous temporal effect, measured by the difference between the number of larvae collected each week ($P < 0.001$). Peaks in larval abundance occurred on week 50, week 55, and week 59. There were still low numbers of larvae present at the end of sampling so it is possible that production of larvae may have continued after sampling finished with subsequent peaks (Fig. 5.2).

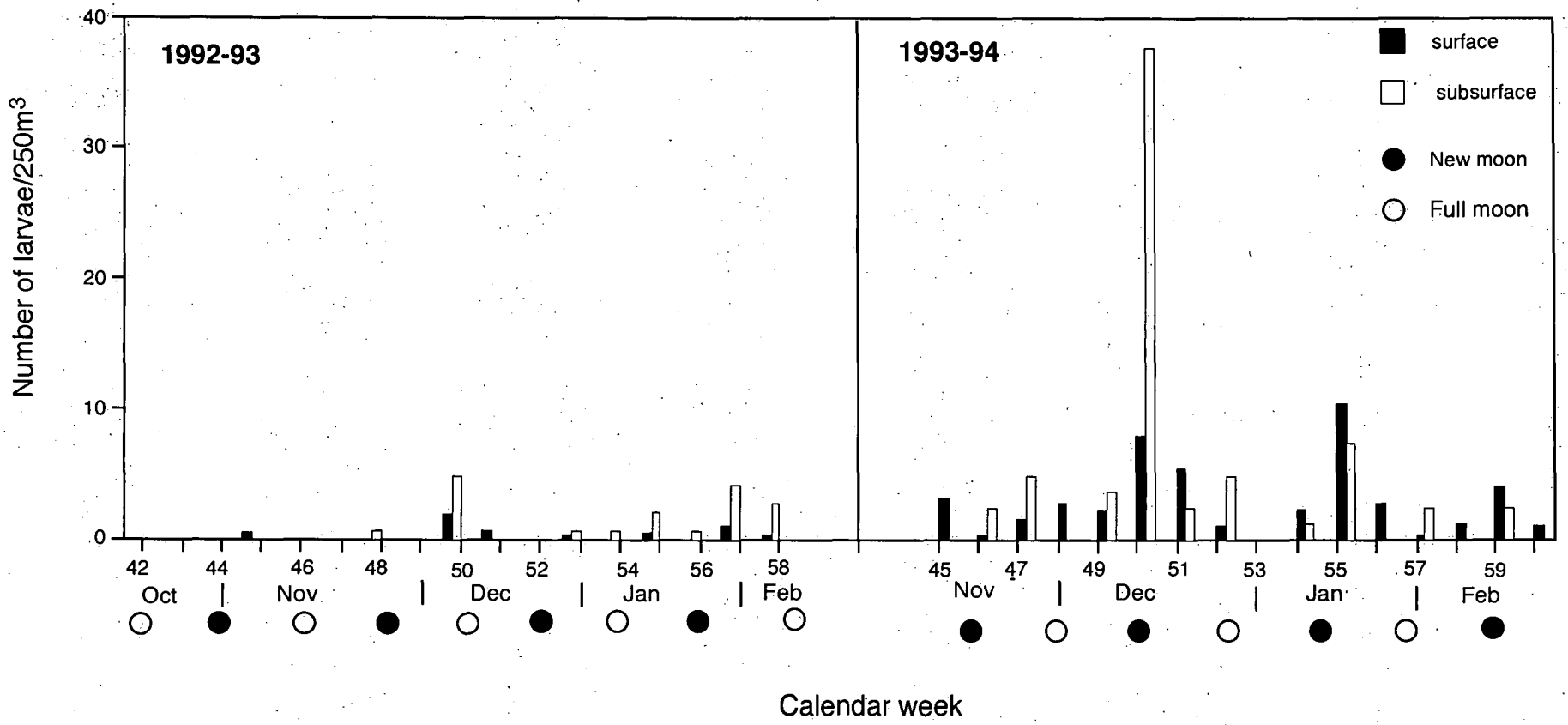

Figure 5.2. The abundance of larvae at Taroona and their relation to lunar cycle during spring/summer in 1992-93 and 1993-94

5.3.2 Effect of Tides on Larval Abundance

The pattern of larval abundance occurring during flood and ebb tides is shown in Fig. 5.3. There appeared to be no effect of tides (flood and ebb tides) on the abundance of larvae when data were pooled for 2 years (38.56% total catch on flood tides and 61.44% total catch on ebb tides, $P > 0.05$) or analysed by separate year (39.56% total catch on flood tides and 60.44% total catch on ebb tides for 1992-93 and 45.92% total catch on flood tides and 54.08% on ebb tides for 1993-94, $P > 0.05$). There was no interaction of depth of towing and tide affecting the abundance of larvae ($P > 0.05$). No effect of tidal was observed after any effects of the lunar cycle was removed ($P > 0.05$).

5.3.3 Effect of Moon Phase on Larval Abundance

The pattern of moon phase in relation to the abundance of larvae is shown in Fig. 5.2. Lunar phase did not appear to affect abundance of larvae ($P > 0.05$) when data were pooled for two years. Within years, there was no effect of moon phase in 1992-93 ($P > 0.05$) but a significant effect on abundance of larvae in 1993-94 was found ($P < 0.05$) with greatest number of larvae occurring on the new moon period (Fig. 5.2). There were relatively few larvae captured in 1992-93 so the lack of consistency between years may be due to low larval supply. Alternatively, interaction of other unfavourable factors such as wave action may have obscured lunar patterns. There was no interaction effect between moon phase and depth of towing on the abundance of larvae in 1993-94 ($P > 0.05$).

The interaction effect between tide and moon phase on the abundance of larvae was also examined. There appeared to be no effect of interaction between tide and moon phase when data were pooled for two years or for separate years ($P > 0.05$).

5.3.4 Effect of Wind on Larval Abundance

Effect of south-easterly wind vector on the abundance of larvae were analysed on daily data only because all larvae collected were aged between 0 and 5 days. It was considered that wind would have little influence at lags of weeks.

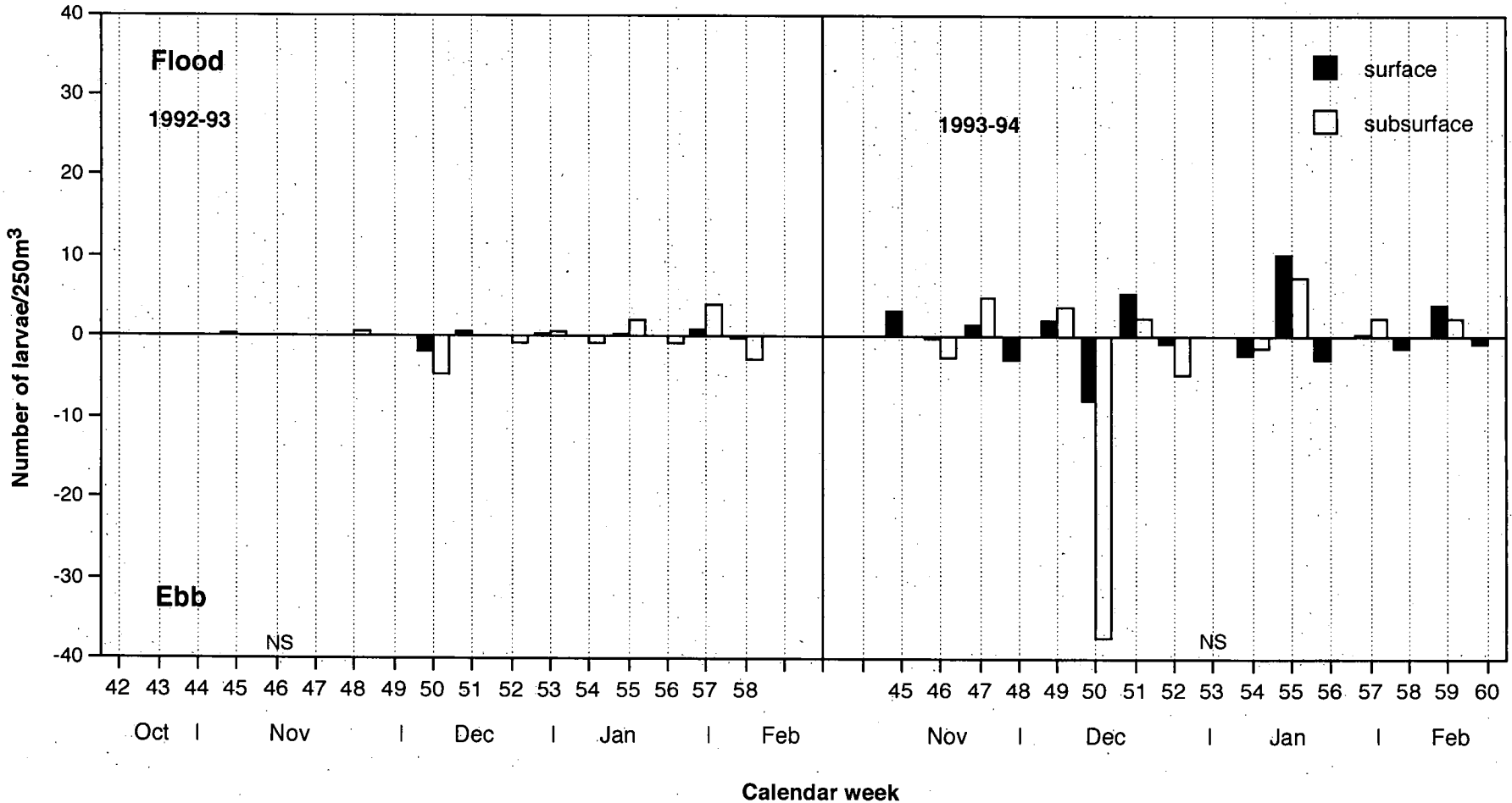

Figure 5.3. Number of larvae collected by surface and subsurface on flood and ebb tides in the Derwent River Estuary during spring/summer 1992-93 and 1993-94. Bar charts show mean number of larvae/250 m^3 (except for larvae at subsurface show total number of larvae due to no replicate); NS: no sampling.

Mean daily south-easterly wind during sampling period in 1992-93 with low larval abundance was 2.63 knots (S.D. = 5.45) and in 1993-94 with high larval abundance was 1.43 knots (S.D. = 6.61). There was no difference in wind strength between years ($P > 0.05$).

Maximum Wind

There appeared to be significant inverse correlation between maximum daily south-easterly wind component at a lag of 5 d and the abundance of larvae (collected at surface, subsurface, and surface and subsurface pooled) when data were pooled for two years (Table 5.1, Fig. 5.4a, 5.4c, and 5.4e). Within years, there was only significant inverse correlation with maximum daily south-easterly wind vector at a lag of 5 d in 1993-94 when data of larvae collected at surface and subsurface were pooled ($r = -0.39$, $P < 0.05$, Table 5.2, Fig. 5.5a). These relationships were also evident in additional analyses where any effect of the lunar cycle was removed.

Mean Wind

There was significant effect of mean daily south-easterly wind on the abundance of larvae at a lag of 5 d when data were pooled for two years and within years ($P < 0.05$). After observing the apparent effect of wind on larval abundance, further analysis was conducted to define the extent of correlation with this variable. The number of larvae (collected at surface, subsurface, and surface and subsurface pooled) was significantly inversely correlated with the mean daily south-easterly wind vector at a lag of 5 d, when data were pooled for two years (Table 5.1, Fig. 5.4b, 5.4d, and 5.4f). Within separate years, there was only significant inverse correlation to mean daily south-easterly wind vector, at lag of 5 d, in the year with high larval abundance in 1993-94, when larvae at surface and subsurface were pooled ($r = -0.49$, $P < 0.05$, $n = 30$, Table 5.2, Fig. 5.5b). These relationships were also evident in additional analyses where any effect of the lunar cycle was removed.

5.3.5 Effect of Rainfall on Larval Abundance

Mean daily rainfall during sampling period in 1992-93 appeared to be lower than 1993-94 ($P = 0.04$, mean = 1.10 mm, S.D. = 2.71, total rainfall = 133.6 mm for 1992-93 and mean = 3.01 mm, S.D. = 9.75, total rainfall = 316.2 mm for 1993-94).

Table 5.1 Correlation (r) value between environmental factors and the abundance of larvae at reasonable lag (days and weeks) when data was pooled for two years. RD = river discharge; RN = rainfall; WND = wind; day and week in bracket show "r" value were analysed by day lag and week lag. * : significant at $P < 0.05$.

Year	Larvae	Factors	0	1	2	3	4	5
1992-93+1993-94	surface	RD (week)	0.20	0.13	0.17	0.13		
		RN (week)	0.20	0.10	0.48*	0.28		
		RN (day)	-0.01	0.03	0.03	0.06	0.07	0.25
		max.WND (day)	-0.23	-0.02	0.06	0.04	-0.24	-0.36*
		mean WND (day)	-0.28	-0.08	-0.03	0.03	-0.22	-0.46*
	subsurface	RD (week)	0.05	-0.14	0.002	-0.21		
		RN (week)	-0.01	-0.08	0.31	-0.18		
		RN (day)	0.09	0.15	-0.11	-0.29	0.077	0.21
		max.WND (day)	-0.04	0.19	0.26	0.23	-0.05	-0.39*
		mean WND (day)	-0.07	0.19	0.25	0.25	-0.002	-0.38*
	surface+subsurface	RD (week)	0.11	-0.02	0.08	-0.05		
		RN (week)	0.08	0.003	0.39*	0.03		
		RN (day)	0.04	0.09	-0.05	-0.13	0.07	0.23
		Max.WND (day)	-0.12	0.09	0.16	0.14	-0.14	-0.37*
		mean WND (day)	-0.19	0.07	0.15	0.18	-0.12	-0.41*

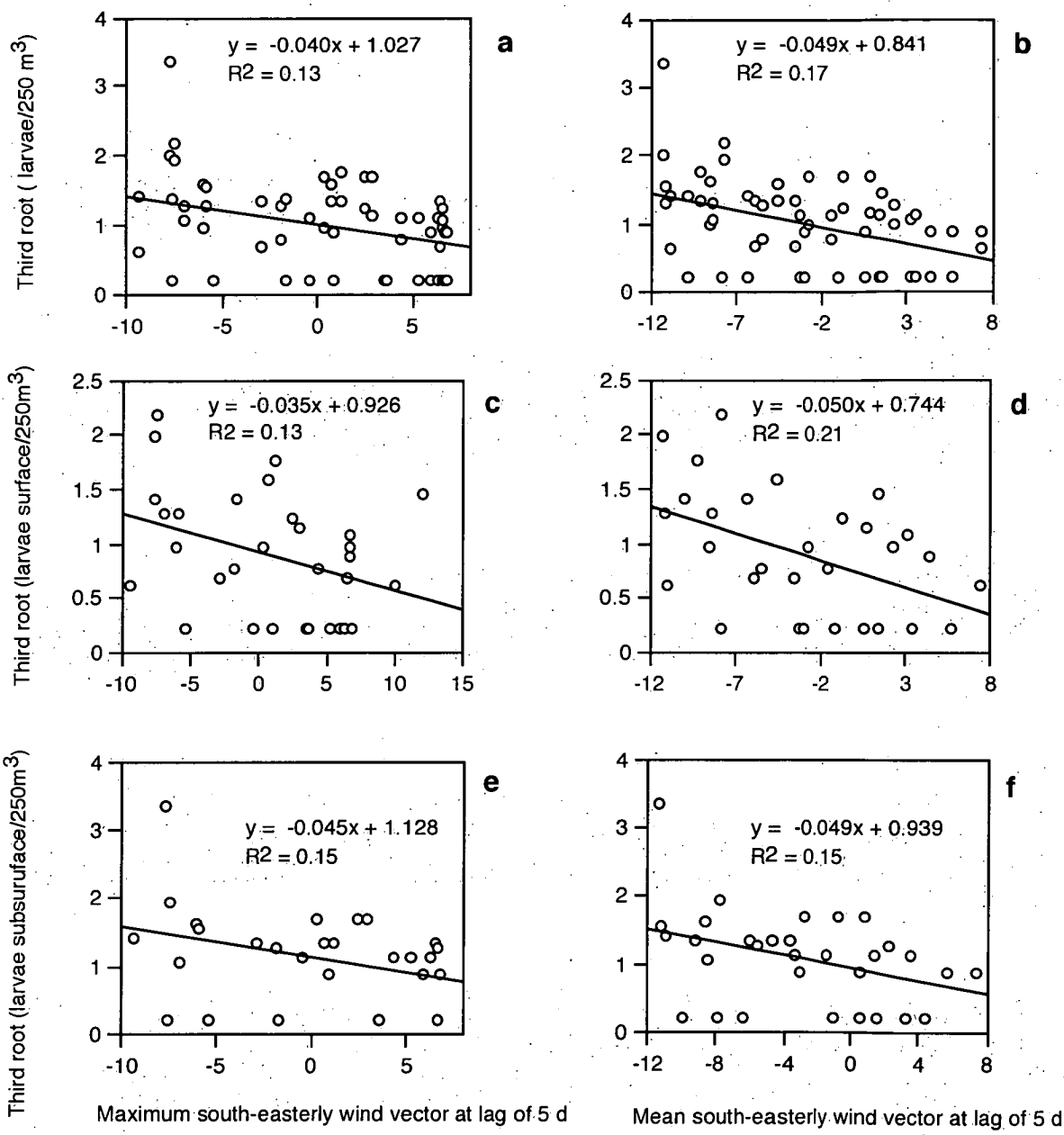

Figure 5.4. Regressions of third root of number of larvae/250m^3 (surface and subsurface pooled) (a-b), larvae surface (c-d), and larvae subsurface (e-f) against maximum and mean south-easterly wind vector at a lag of 5 d when data were pooled for 2 years (1992-93 and 1993-94).

Table 5.2 Correlation (r) value between environmental factors and the abundance of larvae at reasonable lag (days and weeks) when data was analysed within years. RD = river discharge; RN = rainfall; WND = wind; day and week in bracket show r value were analysed by day lag and week lag. * : significant at $P < 0.05$.

Year	Larvae	Factors	0	1	2	3	4	5
1992-93	surface	RD (week)	-0.35	-0.18	-0.36	-0.34		
		RN (week)	0.23	-.28	0.33	0.19		
		RN (day)	0.30	-.05	-0.30	-0.08	0.56*	0.12
		max.WND (day)	0.13	0.19	0.30	0.29	0.03	-0.17
		mean WND (day)	0.19	0.29	0.33	0.29	0.09	-0.16
	subsurface	RD (week)	-0.10	0.05	-0.22	-0.16		
		RN (week)	0.30	-0.31	0.24	-0.24		
		RN (day)	0.17	-0.12	0.04	0.16	0.39	0.29
		max.WND (day)	-0.25	0.22	0.08	0.05	0.04	-0.29
		mean WND (day)	-0.18	0.24	0.15	-0.01	0.10	-0.29
	surface+subsurface	RD (week)	-0.18	-0.04	-0.24	-0.20		
		RN (week)	0.24	-0.26	0.24	-0.05		
		RN (day)	0.19	-0.08	-0.08	0.05	0.40*	0.19
		Max.WND (day)	-0.08	0.18	0.15	0.13	0.03	-0.21
		mean WND (day)	-0.03	0.30	0.26	0.13	0.11	-0.27
1993-94	surface	RD (week)	0.32	-0.03	0.21	-0.14		
		RN (week)	0.06	-0.06	0.53*	0.13		
		RN (day)	-0.23	-0.15	0.21	-0.04	0.03	0.04
		Max.WND (day)	-0.20	-0.04	-0.25	-0.01	-0.15	-0.43
		mean WND (day)	-0.24	-0.12	-0.34	0.006	-0.06	-0.47
	subsurface	RD (week)	0.03	-0.33	0.02	-0.39		
		RN (week)	-0.20	-0.13	0.29	-0.29		
		RN (day)	0.07	0.17	-0.29	-0.50*	-0.44	0.12
		Max.WND (day)	0.19	0.21	0.37	0.38	-0.003	-0.40
		mean WND (day)	0.13	0.24	0.35	0.48*	0.06	-0.38
	surface+subsurface	RD (week)	0.13	-0.22	0.08	-0.29		
		RN (week)	-0.11	-0.10	0.35*	-0.14		
		RN (day)	-0.03	0.06	-0.11	-0.33	-0.27	0.09
		Max.WND (day)	0.05	0.12	0.15	0.24	-0.05	-0.39*
		mean WND (day)	-0.002	0.14	0.13	0.38	0.03	-0.49*

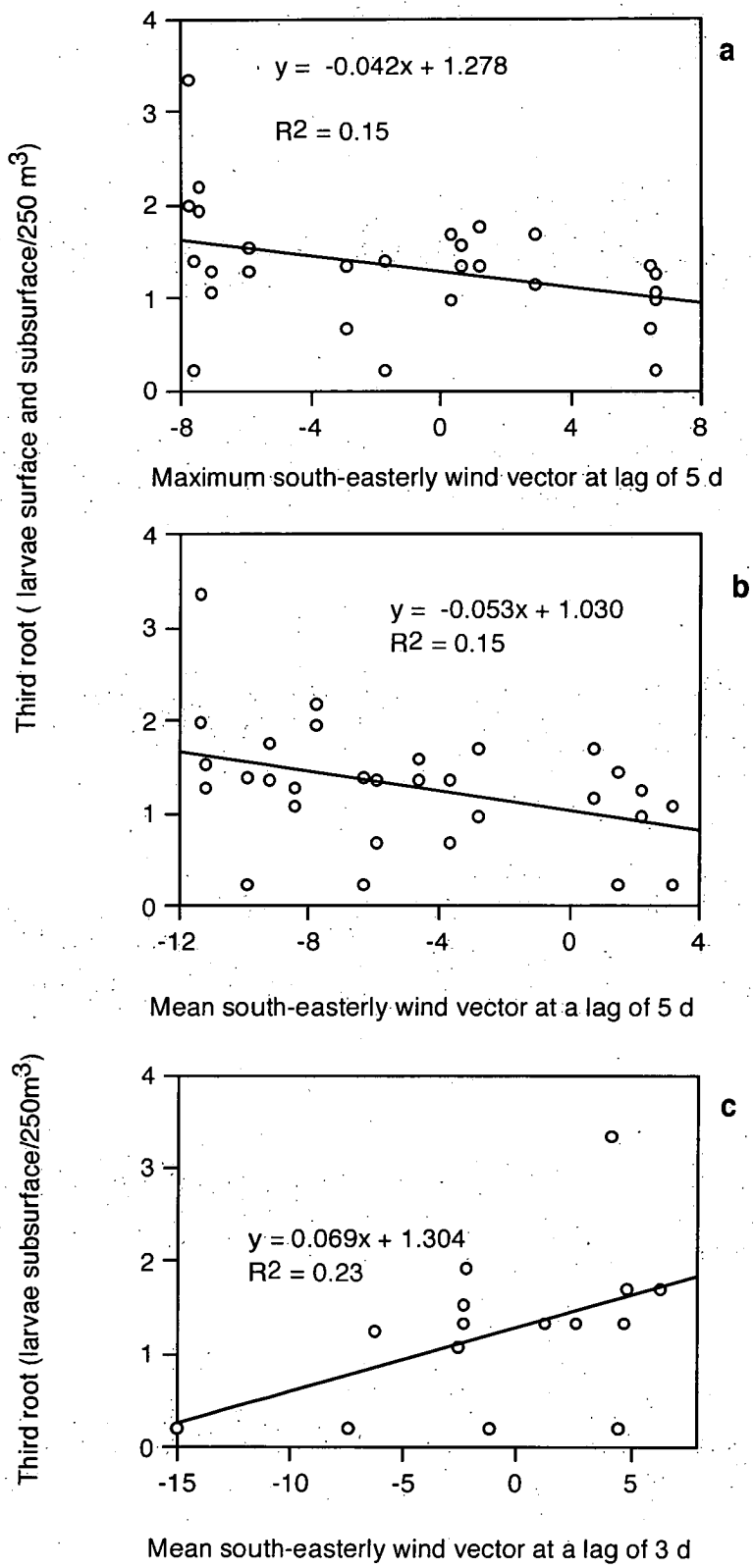

Figure 5.5. Regressions of third root of number of larvae (surface and subsurface pooled)/250 m^3 against maximum and mean south-easterly wind vector at a lag of 5 d (a-b) and larvae subsurface/250 m^3 against mean south-easterly wind vector at a lag of 3 d (c) in 1993-94.

There appeared to be no consistent effect of rainfall on the abundance of larvae at lags of days or weeks, when data were pooled for two years or when data were analysed for separate years ($P > 0.05$). In additional analyses, where any effect of the lunar cycle was removed, there appeared to be a weak effect of rainfall at a lag of 5 d ($P < 0.057$). This may be associated with the observed negative correlation between wind and larval abundance at a lag of 5 d.

Correlations between the abundance of larvae and rainfall at daily and weekly lags are shown in Table 5.1 and 5.2. When data were pooled for two years, there were significant correlation at a lag of 2 w for larvae collected at surface, and when the number of larvae collected at the surface and subsurface were pooled (Table 5.1, Fig. 5.6a and 5.6b). Within separate years, there were significant correlation at a lag of 4 d for larvae collected at surface ($r = 0.56$, $P < 0.05$, Table 5.2, Fig. 5.7a) and when larvae surface and subsurface pooled ($r = 0.40$, $P < 0.05$, Table 5.2, Fig. 5.7b) in 1992-93. In 1993-94, there were significant correlation between weekly rainfall at a lag of 2 w and larvae at surface and larvae at surface and subsurface pooled (Table 5.2, Fig. 5.8a and 5.8b). There was also significant correlation between daily rainfall at a lag of 3 d when larvae collected at the surface and subsurface were pooled ($r = -0.50$, $P < 0.05$, Table 5.2, Fig. 5.8c).

5.3.6 Effect of River Discharge on Larval Abundance

Mean river discharge in 1992-93 was significantly lower than in 1993-94 ($P < 0.05$, mean = 67.75 m^3/s, S.D. = 27.59, and total river discharge = 8197.62 m^3/s for 1992-93 and mean = 90.31 m^3/s, S.D. = 48.44, and total river discharge = 9482.15 m^3/s).

Results of stepwise multiple regression showed no consistent effect of river discharge on the abundance of larvae when analysed for: data pooled across years and within years at reasonable weekly lags ($P > 0.05$). No analysis for daily data were calculated because daily river discharge was not strong enough to affect the abundance of larvae. The site where river discharge is recorded is located a long way from the sampling site (Taroona, 75 km approximately) so any relationship may have become blurred.

Correlations of abundance of larvae with river discharge at a reasonable weekly lag are shown in Table 5.1 and 5.2. There appeared to be no

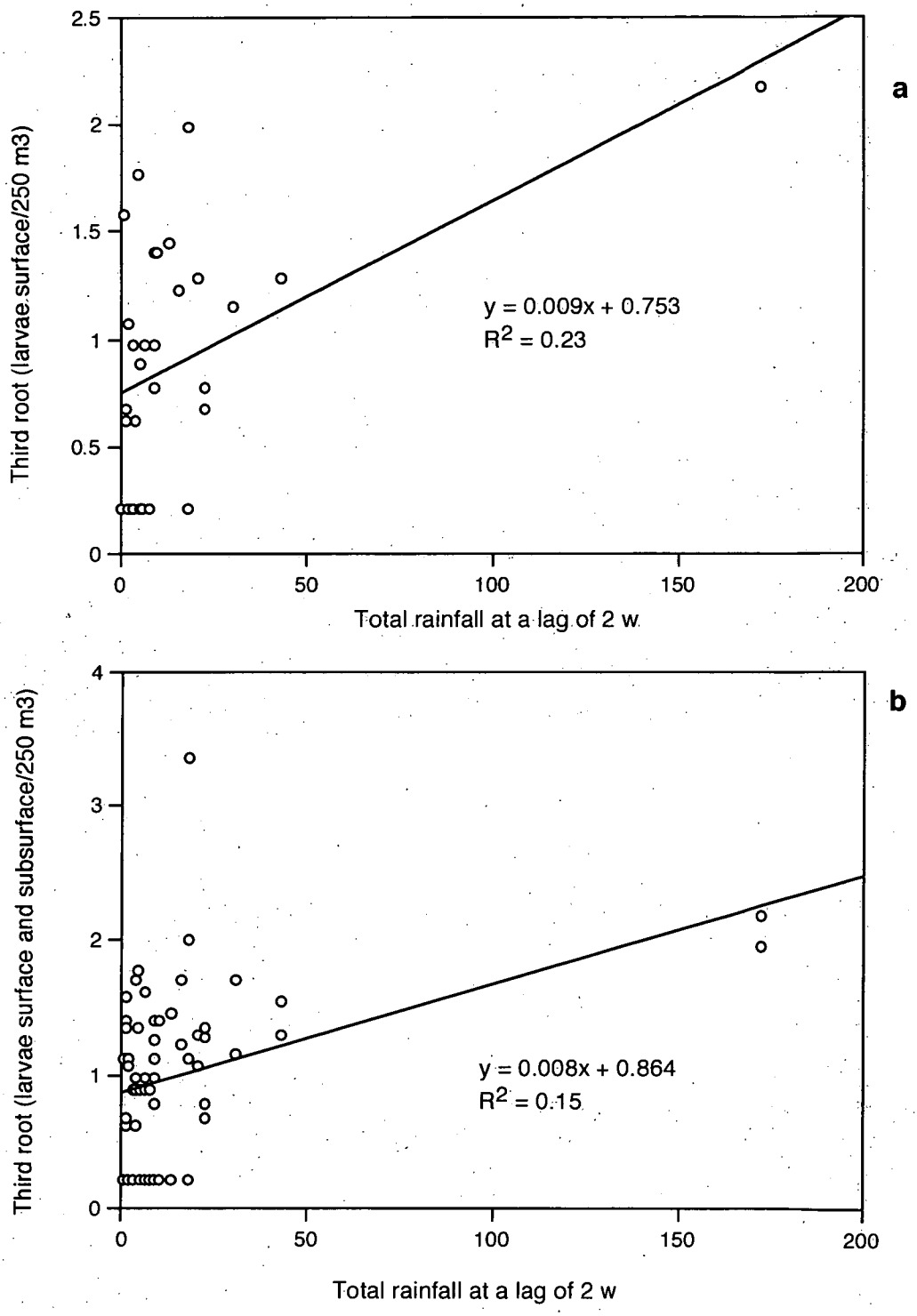

Figure 5.6. Regressions of third root of number of larvae surface/250 m^3 (a) and larvae at surface and subsurface pooled/250 m^3 (b) against total rainfall at a lag of 2 w when data were pooled for 2 years.

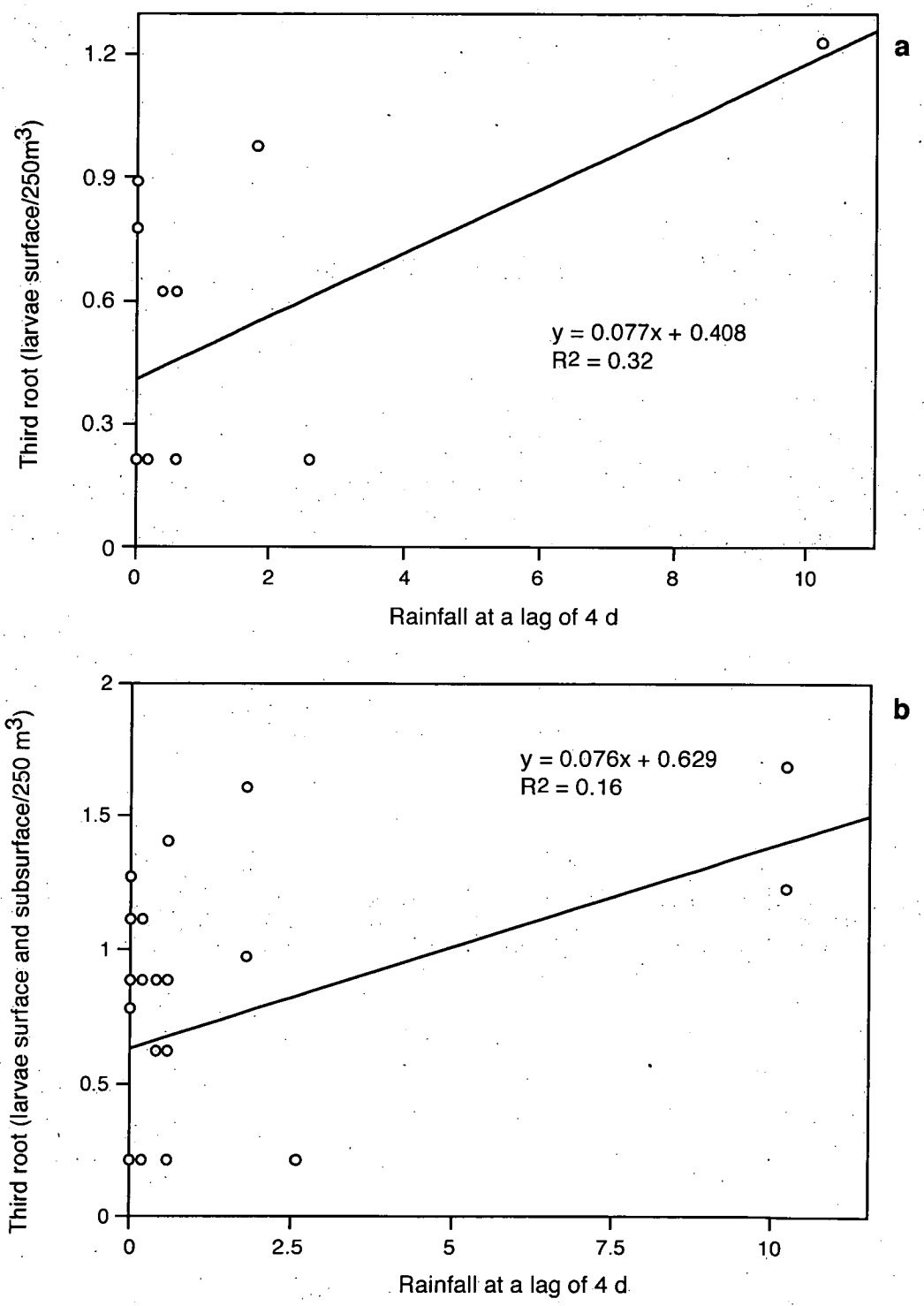

Figure 5.7. Regressions of third root of number of larvae surface/250 m^3 (a) and larvae surface and subsurface pooled/250 m^3 (b) against rainfall at a lag of 4 d in 1992-93.

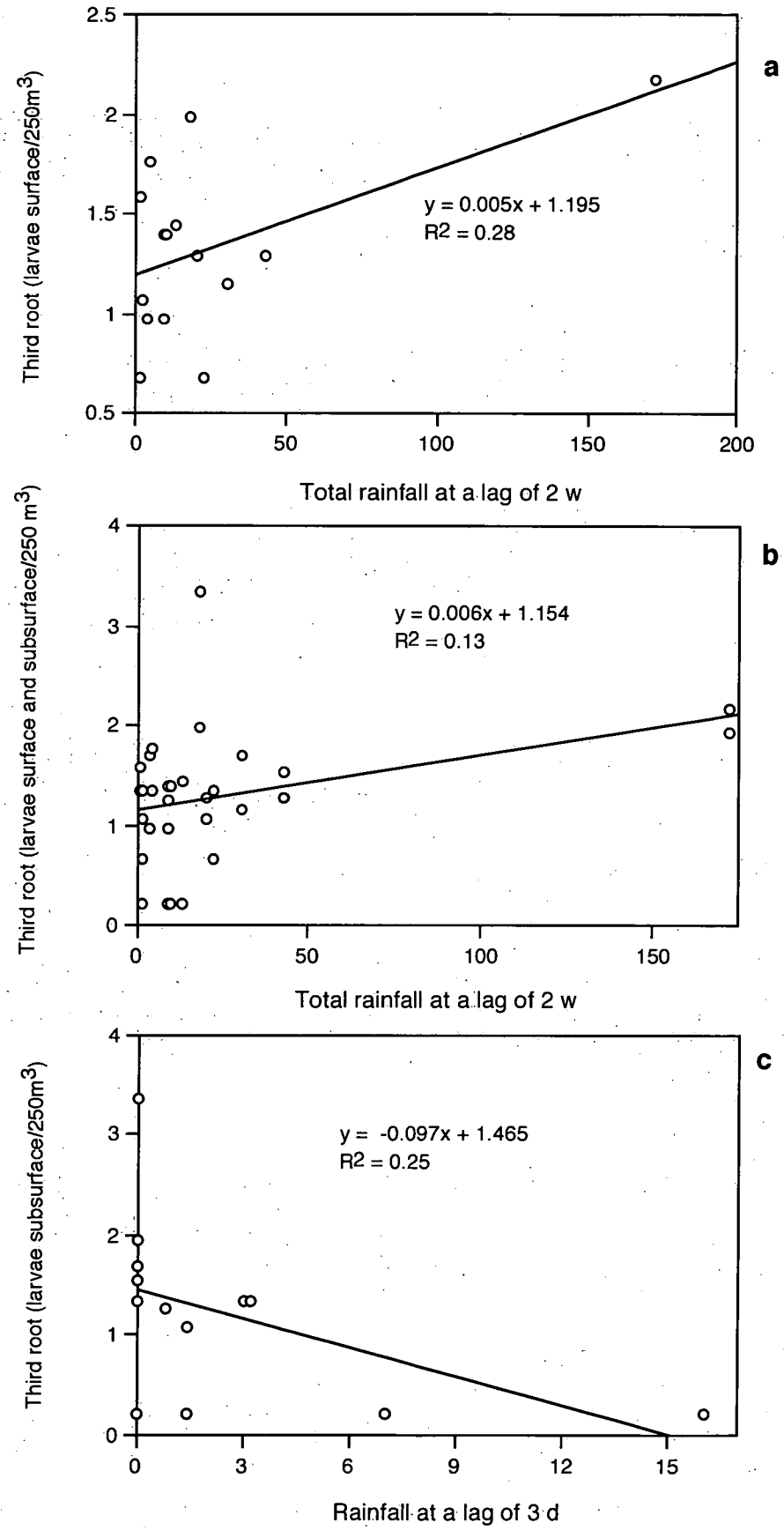

Figure 5.8. Regressions of third root of number of larvae surface/250 m^3(a) and larvae surface and subsurface pooled/250 m^3 (b) against total rainfall at a lag of 2 w ar larvae at subsurface against rainfall at a lag of 3 d (c) in 1993-9.

significant correlation at reasonable lags for data pooled for both years and for separate years. No effect was observed for both raw data, and after lunar effect was removed.

5.3.7 Effect of Temperature and Salinity on the Abundance of Tasmanian blenny larvae

Temperature and salinity measurements during spring/summer are shown in Fig. 5.9a for two consecutive years, 1992-93 and 1993-94. The temperature gradually increased over the sampling period in 1992-93 while in 1993-94, temperature fluctuated markedly over the sampling period. There were three distinct peaks in 1993-94 separated by decline for a couple of weeks (Fig. 5.9a). Mean surface temperature during the study period were similar for each year, although it averaged 0.4°C higher in 1993-94 than in 1992-93 (ranged from 11.6°C to 19.2°C, mean = 15.3°C, S.D. = 2.08 in 1992-93 and ranged from 13.1°C to 18.0°C, mean = 15.7°C, S.D. = 1.46 in 1993-94).

Salinity during the study period was very similar in each year and ranged from 30 to 34.3‰, mean = 32.7‰, S.D. = 1.32 in 1992-93 and from 30.1 to 33.8‰, mean = 32.4‰, S.D. = 1.23 in 1993-94. A marked decline in salinity was consistent with a marked rise in temperature during weeks 43, 50, 53 and 56 in 1992-93 and during weeks 47-48, 55 and 59 in 1993-94 (Fig. 5.9a). This indicates a flow of relatively warm, low salinity water over the region.

Peaks of larvae during the sampling period appeared to correspond to increases in temperature and declining salinity, especially in 1993-94 (Fig. 5.9a and 5.9b). Results of stepwise multiple regression showed an effect of temperature on the abundance of larvae when data were pooled for all years ($P < 0.05$), but no effect of temperature for separate years. In analysis of raw data, there appeared to be no effect of salinity on the abundance of larvae when data were pooled for all years or for separate years ($P > 0.05$).

When temperature and salinity were analysed separately, there appeared to be an effect of temperature, salinity, and interaction on the abundance of larvae when data were pooled for all years ($P < 0.05$). There appeared to be no interaction between these terms and depth of sampling on the abundance of larvae ($P > 0.05$). Consequently, larvae collected at surface

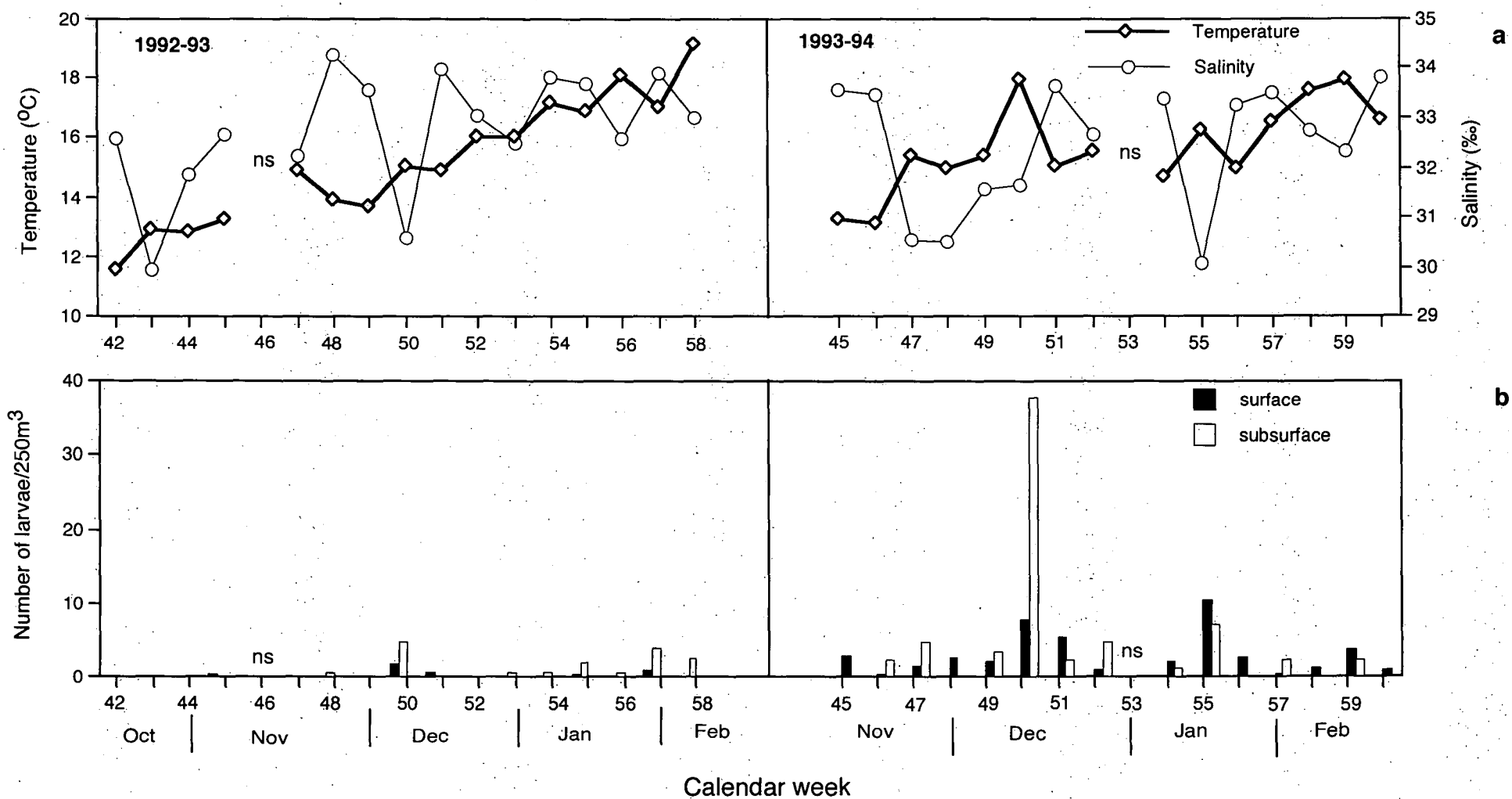

Figure 5.9. Record of surface temperature and salinity (a) and the abundance of blenny larvae (b) from Taroona site during spring/summer in 1992-93 and 1993-94; ns = no sampling.

and subsurface were pooled to determined their correlations with temperature and salinity.

There appeared to be an effect of temperature, salinity, and interaction of temperature and salinity on the abundance of larvae in 1993-94 although not in 1992-93 ($P < 0.05$). These relationships were also evident in additional analyses where any effect of the lunar cycle was removed.

The correlations with these two factors were analysed. The abundance of larvae was significantly positively correlated to temperature and significantly inversely correlated to salinity when data were pooled for all years ($r = 0.26$, $P < 0.05$, $n = 62$ for temperature, Fig. 5.10a and $r = -0.30$, $P < 0.05$, $n = 62$ for salinity, Fig. 5.10b).

In 1993-94, there appeared to be a trend of correlation between temperature and the abundance of larvae ($r = 0.32$, $P > 0.05$, $n = 30$), but there was significant inverse correlation between salinity and the abundance of larvae ($r = -0.38$, $P < 0.05$, $n = 30$, Fig. 5.10c).

5.3.8 Intensive Larval Fish Sampling

Surface temperature and salinity at nearshore and offshore locations are shown in Fig. 5.11. Location seemed to have little effect on temperature or salinity.

Based on temperature and salinity measurements, there appeared to be three water masses in this study. The first was a water mass characterised by low temperature and high salinity at Taroona. The mean temperature was 15.9°C and mean salinity was 31.9‰ (Fig. 5.11).

The second characterised by intermediate temperature and intermediate salinity at Tranmere. The mean temperature was 16.4°C and mean salinity was 29.9‰ (Fig. 5.11).

The third was characterised by high temperature and low salinity at Sandy Bay Point and Kangaroo Bluff. The mean temperature at Sandy Bay Point was 17.6°C and mean salinity was 27.3‰ while at Kangaroo Bluff the mean temperature was 17.9°C and mean salinity was 25.3‰ (Fig. 5.11).

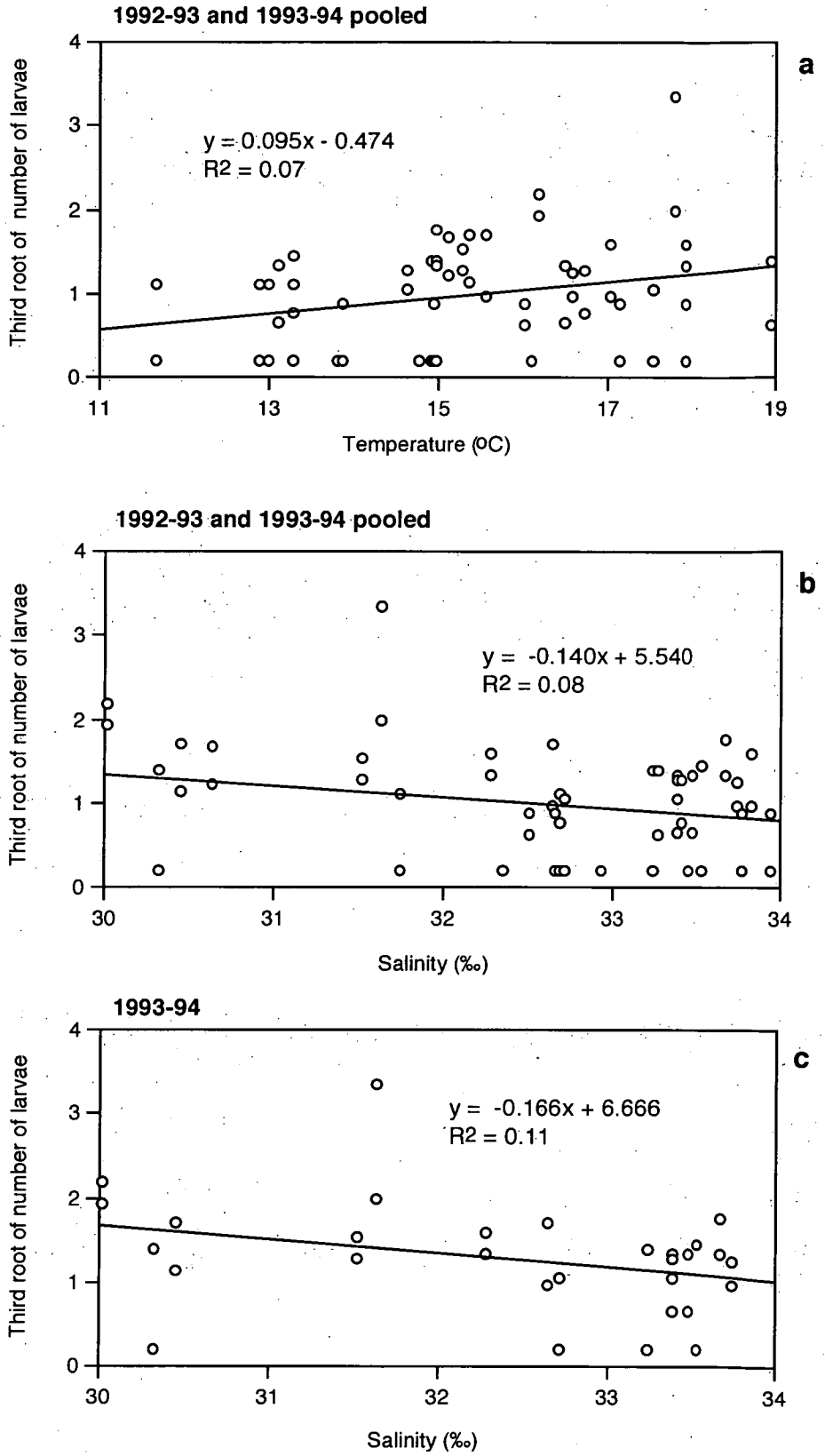

Figure 5.10. Regressions of temperature and salinity against third root of number of larvae when data were pooled for two years (a and b) and regression of salinity against third root of number of larvae in 1993-94 (c).

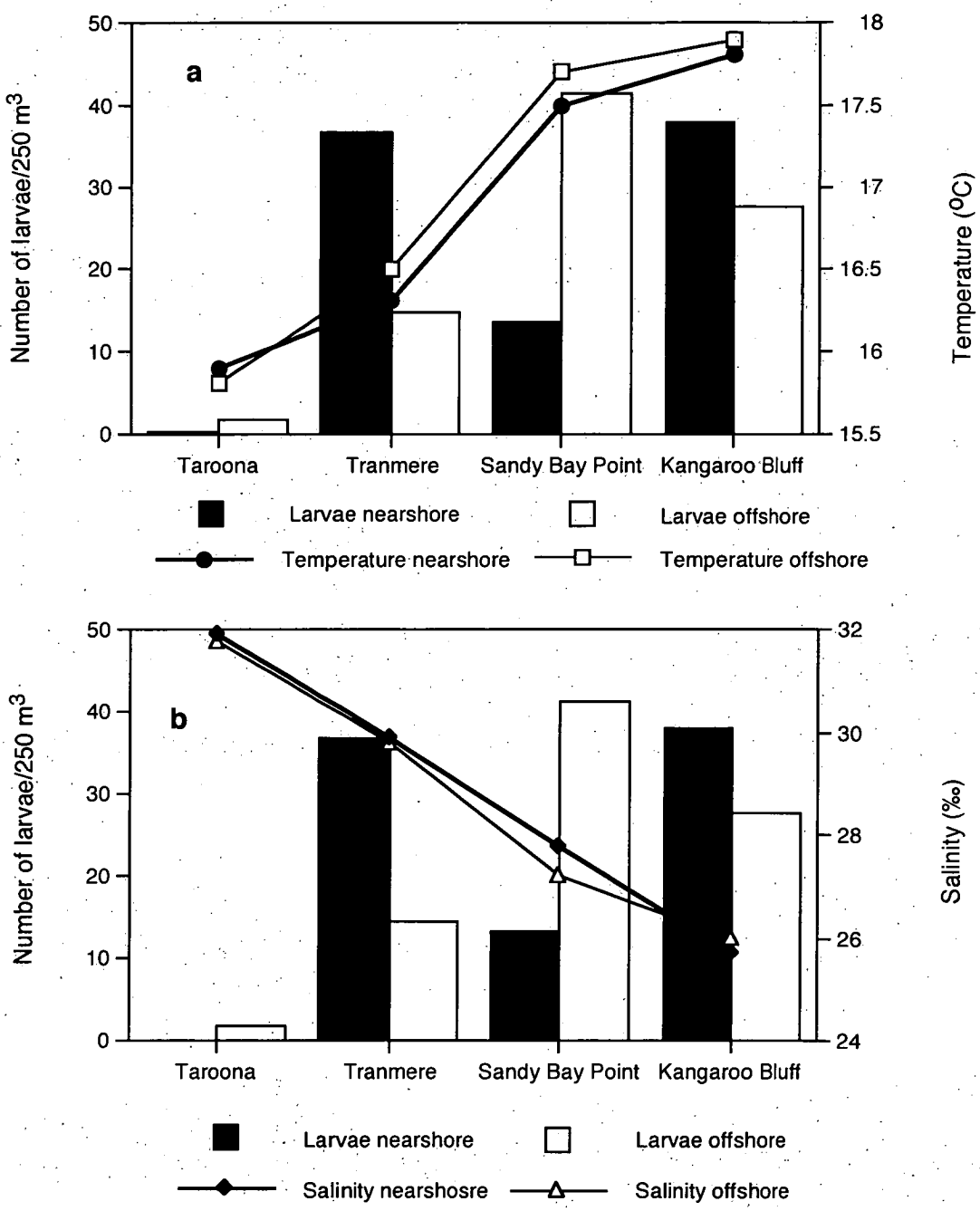

Figure 5.11. The abundance of larvae in relation to temperature (a) and salinity (b) sampled from 4 sampling sites in Derwent Estuary on 8 January 1996

Larvae were most abundant at Kangaroo Bluff (n = 131.36 larvae/250 m^3, mean = 32.84 ± 6.07, Fig. 5.11), followed by Sandy Bay Point (n = 109.54 larvae/250 m^3, mean = 27.38 ± 16.58, Fig. 5.11), Tranmere (n = 102.65 larvae/250 m^3, mean = 25.66 ± 12.80, Fig. 5.11), and Taroona (n = 3.91 larvae/250 m^3, mean = 0.98 ± 1.26, Fig. 5.11). The abundance of larvae significantly differed between sites ($P < 0.0001$), but there appeared to be no effect of nearshore and offshore locations ($P > 0.05$). However, there was an significant effect of interaction of site and nearshore/offshore location on the abundance of larvae ($P < 0.0001$). Consequently, the relationship between abundance of larvae and temperature and salinity were determined separately for nearshore and offshore locations.

The larvae at nearshore locations were most abundant in the water mass characterised by high temperature and low salinity (Kangaroo Bluff and Sandy Bay Point) and in the water mass with intermediate temperature and intermediate salinity (Tranmere) (Fig. 5.11). The least larvae in nearshore samples were collected from the water mass characterised by low temperature and high salinity (Taroona) (Fig. 5.11). Although there was a statistically significant interaction between site and nearshore/offshore location, the overall trend of larval abundance of offshore samples was essentially the same as that for nearshore samples (Fig. 5.11). Nearshore/offshore location has already been shown to have no significant effect on larval abundance when analysed without salinity or temperature terms. Clearly, the observed interaction effect with site is relatively minor, albeit significant.

When data were analysed without the nearshore/offshore location interaction, there appeared to be a significant effect of temperature, salinity, and their interaction on the abundance of larvae ($P < 0.05$). This analysis used daily data which is sensitive to fluctuations over small time periods; sudden changes in temperature, salinity, or larval abundance could occur coincidentally resulting in spurious significant results. To check this, the relationships between mean temperature and mean salinity and the mean abundance of larvae were then analysed. There appeared to be a trend of positive correlation between mean temperature and mean abundance of larvae although this was not significant ($r = 0.66$, $P > 0.05$, $n = 8$, Fig. 5.12a). Mean salinity did appear to have a significant inverse correlation with mean abundance of larvae ($r = -0.73$, $P < 0.05$, $n = 8$, Fig. 5.12b).

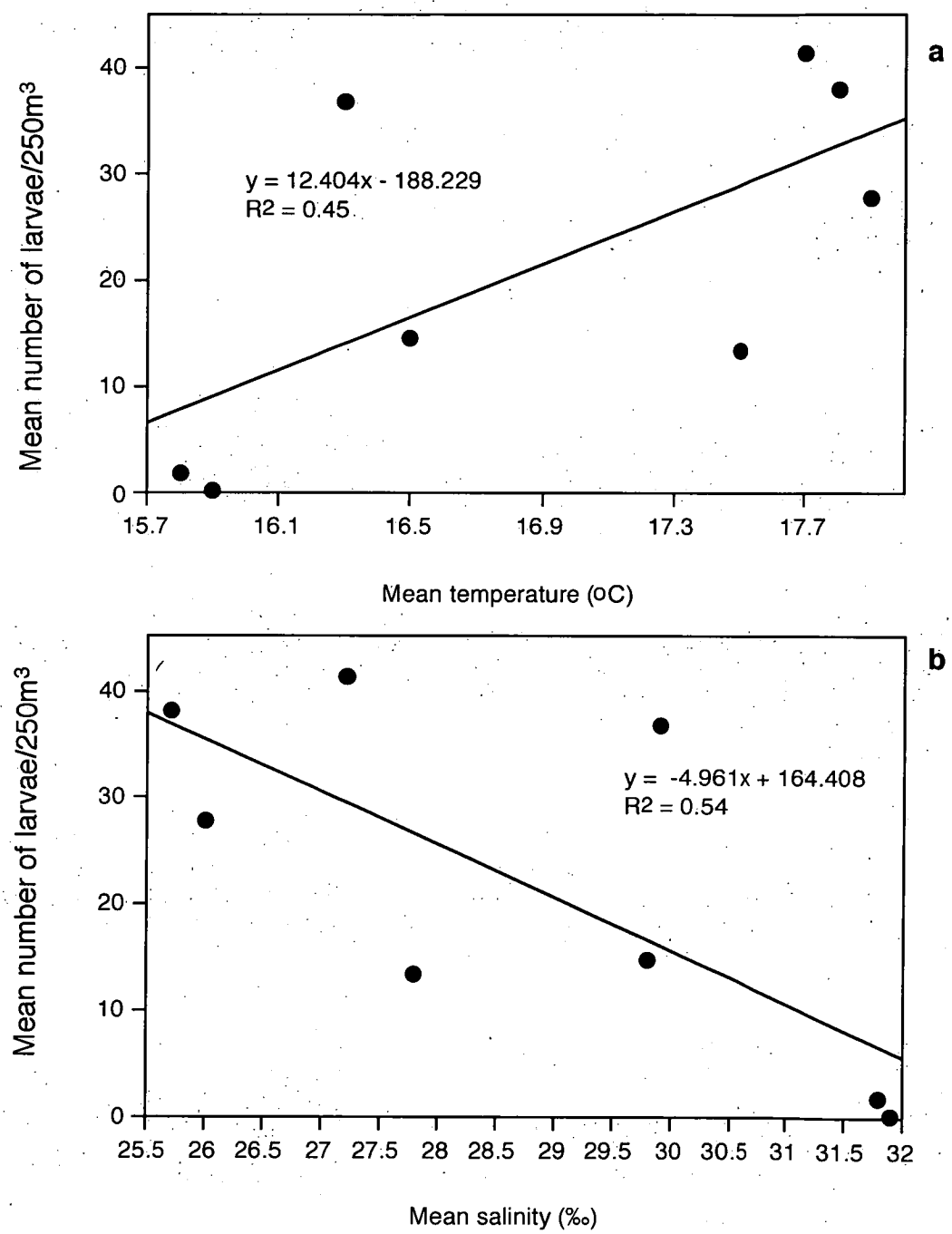

Figure 5.12. Regressions of mean water temperature (a) and mean water salinity (b) against mean number of larvae/250 m^3 collected on 8 January 1996.

5.3.8.1 Length Frequency of Larvae in Different Water Mass

Length frequency of larvae collected at each site is shown in Fig. 5.13, and size range and mean length of larvae of each site is shown in Table 5.3. Sample size from Taroona was small (n = 11) so this site was not included in analyses. Larvae from Sandy Bay Point were significantly smaller than those from other sites ($P < 0.05$) while larvae from Kangaroo Bluff and Tranmere Point were not significantly different in length ($P > 0.05$, Table 5.3). Larvae collected offshore were significantly larger than those collected from nearshore ($P < 0.05$).

Large larvae were rarely caught with only 16 flexion stage larvae captured. These accounted for 1.9% of total number of larvae collected and ranged from 6.7 to 9.1 mm SL (4 larvae from Kangaroo Bluff, 3 larvae from Sandy Bay Point, 7 larvae from Tranmere Point, and 2 larvae from Taroona). The largest larvae was collected at the offshore location of Kangaroo Bluff (Fig. 5.13b).

5.3.9 Growth Rate

5.3.9.1 Growth Rate of Larvae in 1992-93 and 1993-94

Otolithic age was determined for 38 larvae in 1992-93 and 98 larvae in 1993-94. Growth trajectories (length-at-otolithic age) were fitted by linear regression. A term for additional curvature (polynomial) was trialed but did not significantly improve model fit, so simple linear regression was used to explain the relationship for both years (Fig. 5.14). These regressions accounted for 68% of the variance in length at age in 1992-93 and 55% of the variance in 1993-94. The slope of the semilog regression was slightly steeper in 1993-94 (0.35 mm/d) than in 1992-93 (0.23 mm/d) (ANCOVA, $P < 0.01$) which suggests that growth was more rapid in 1993-94.

5.3.9.2 Growth Rate of Larvae from Intensive Sampling Programme

Otolithic age was determined for:

- 23 larvae from Kangaroo Bluff;
- 77 larvae from Sandy Bay Point;
- 67 larvae from Tranmere Point;
- and 11 larvae from Taroona.

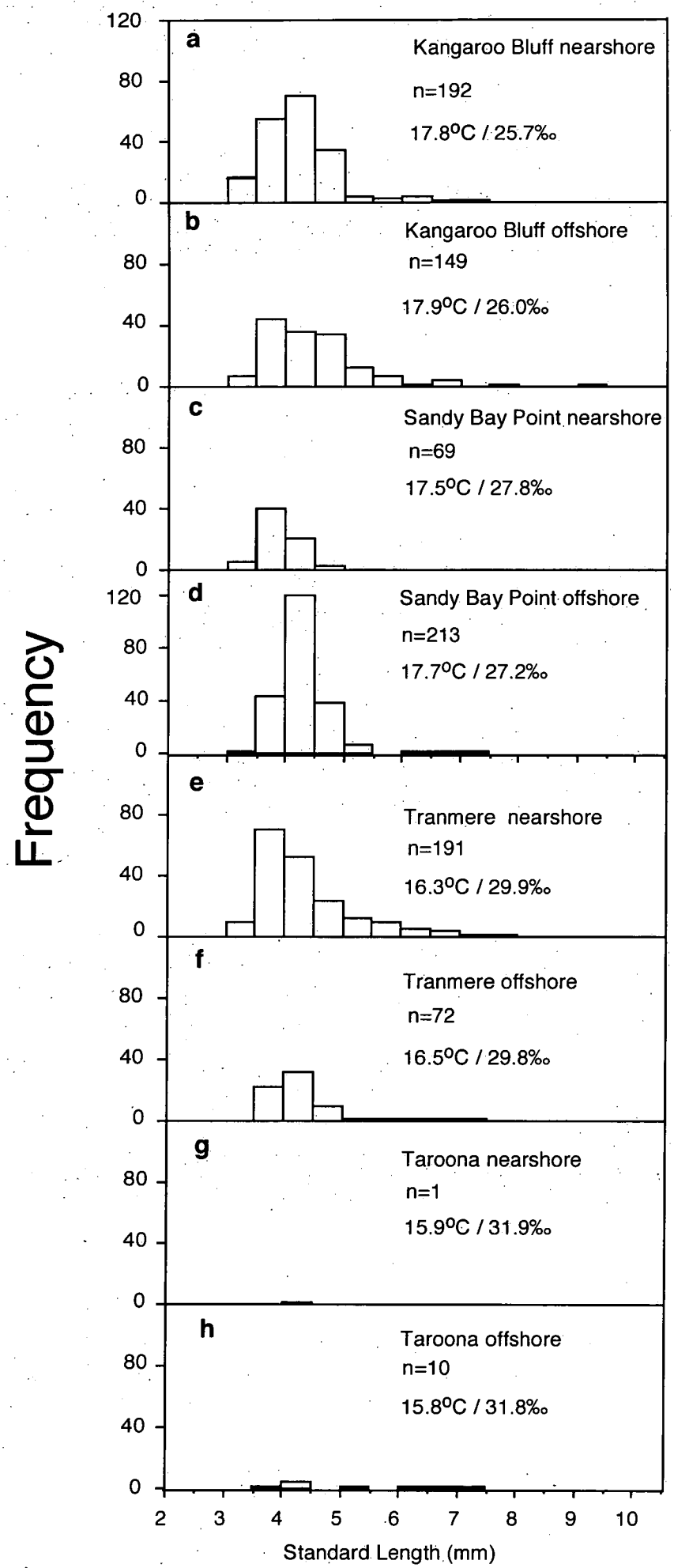

Figure 5.13. Length frequency distribution of larvae collected from 4 sites in Derwent Estuary on 8 January 1996

Table 5.3 Length frequency of larvae collected from 4 sites in Derwent River Estuary on 8 January 1996

Site	Distance from shore	Size range (mm)	Number of larvae	mean	SD
Kangaroo Bluff	nearshore	3.2-7.4	192	4.2	0.66
	offshore	3.3-9.1	149	4.4	0.88
Sanday Bay Point	nearshore	3.0-4.8	69	3.8	0.35
	offshore	3.2-7.0	213	4.2	0.49
Tranmere	nearshore	3.2-8.0	191	4.3	0.84
	offshore	3.5-7.3	72	4.3	0.72
Taroona	nearshore	4	1		
	offshore	3.5-7.0	10	4.9	1.26

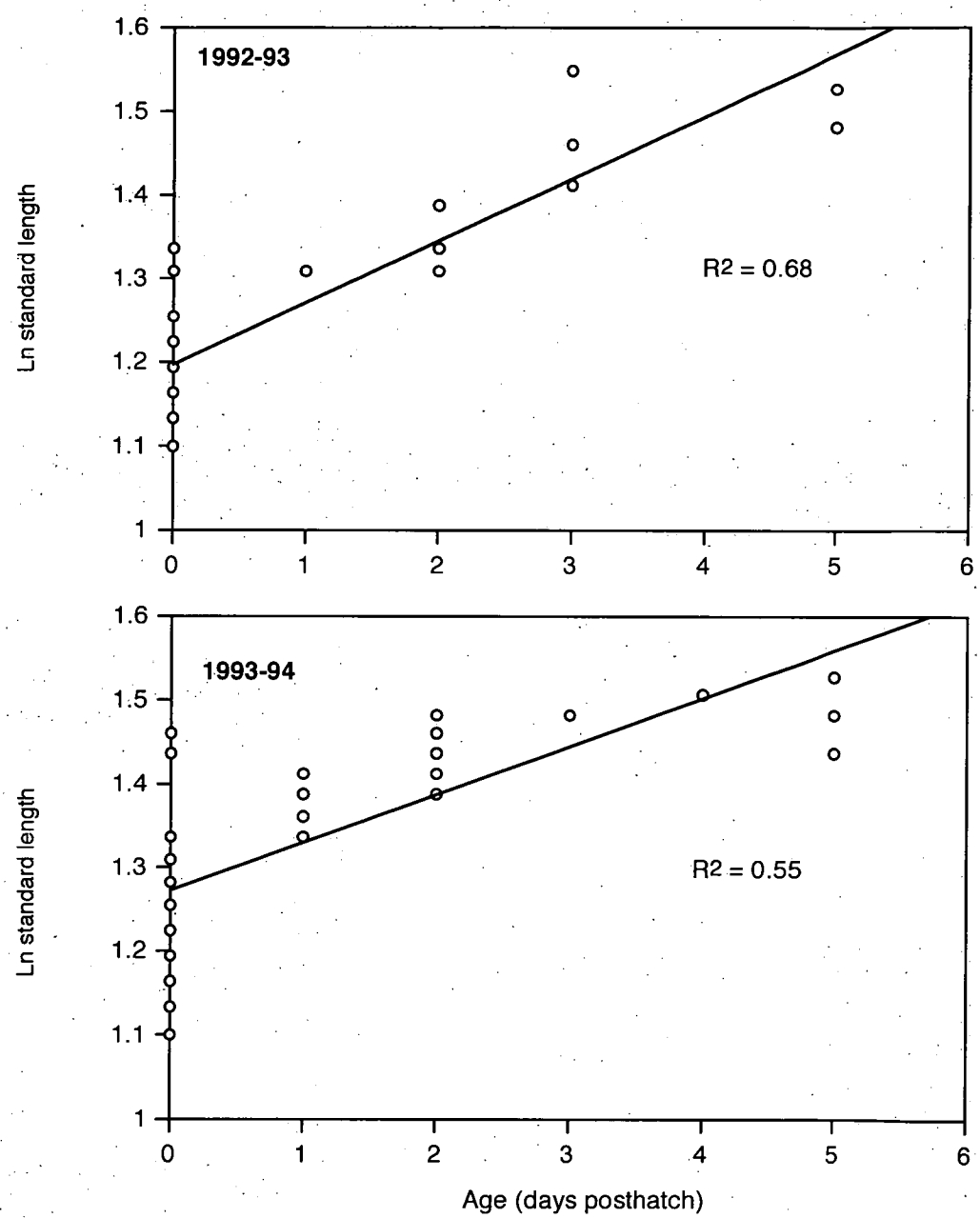

Figure 5.14. Regressions of ln standard length against age (days posthatch) for larvae of blennies collected in 1992-93 and 1993-94. A semilog regression accounts for 68% of the variance in length at age in 1992-93 and 55% of the variance in 1993-94. Differences between years in the slopes of the regression are significant at $P < 0.01$.

Growth trajectories (length-at-otolithic age) appeared to best explained by ln linear regressions for all four sites (Fig. 5.15), and these regressions accounted for:

- 89% of the variance in length at age for Kangaroo Bluff;
- 85% of the variance for Sandy Bay Point;
- 85% of the variance for Tranmere;
- and 87% of the variance for Taroona.

The slopes of these semilog regressions were significantly different for all four sites (ANCOVA, $P < 0.0001$) and were steepest at Kangaroo Bluff (0.333 mm/d), followed by Sandy Bay Point (0.263 mm/d), Taroona (0.251 mm/d), and Tranmere (0.164 mm/d). This suggests that growth was most rapid at Kangaroo Bluff and slowest at Tranmere (Fig. 5.16).

5.3.9.3 The Relationship between Temperature and Growth Rate of Larvae

Larvae caught in 1992-93 and 1993-94

Growth (mm/day) of larvae in 1992-93 and 1993-94 (analysed separately) did not appear to be affected by the natural temperature ranges experienced in the field ($r = 0.33$ for 1992-93, and $r = 0.22$ for 1993-94, $P > 0.05$). This pattern remained the same when data for the two years was pooled ($r = 0.18$, $P > 0.05$).

Larvae from intensive larval fish sampling

The relationship between temperature and growth of larvae sampled during the intensive larval sampling programme were not analysed for separate sites because the range of temperature was small. However, when data were pooled for all four sites, a significant relationship between temperature and growth of larvae was found, with larvae growing more rapidly at higher temperatures ($r = 0.37$, $P < 0.0001$, Fig. 5.17).

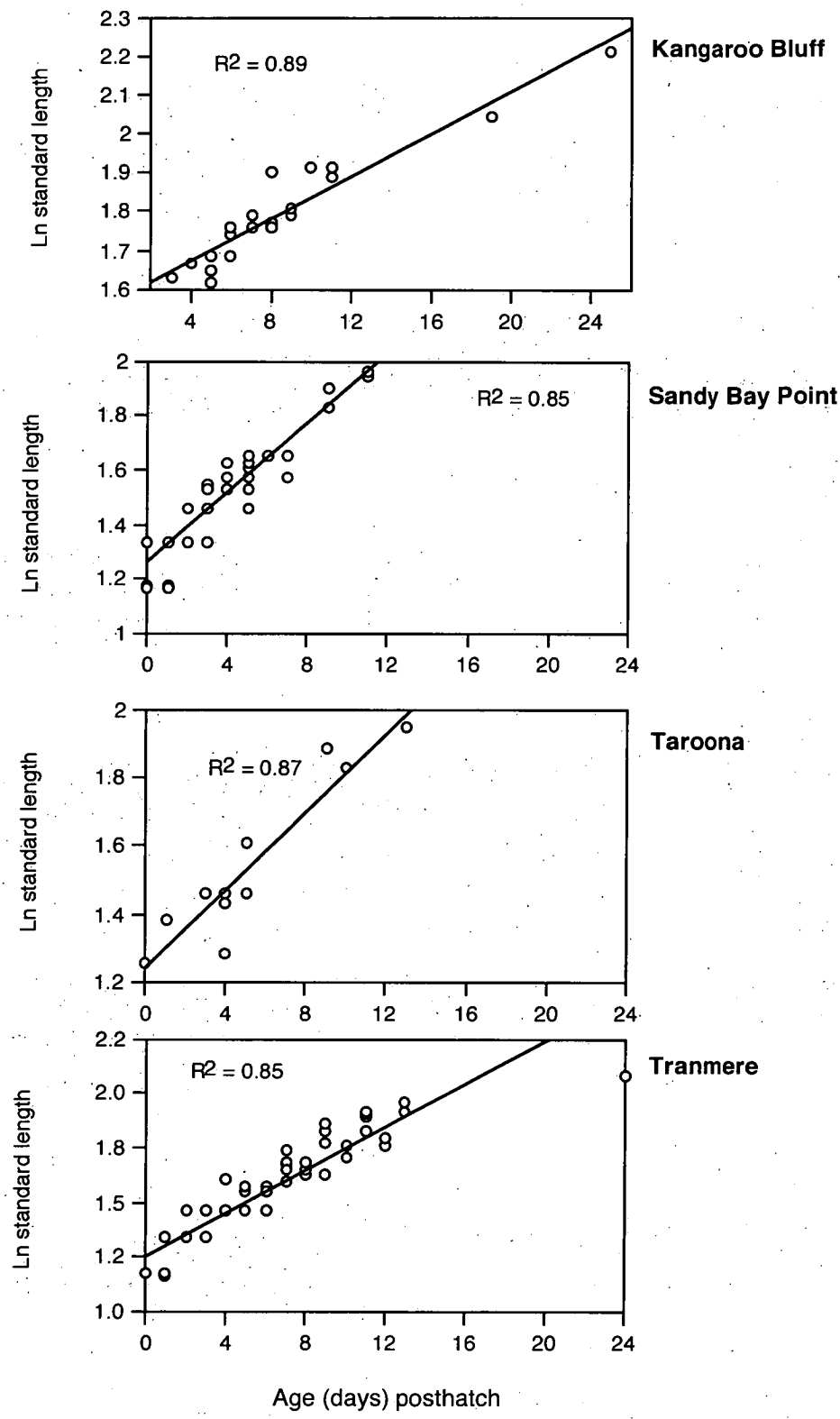

Figure 5.15. Regressions of ln standard length against age (day posthatching) for larvae of blennies collected from Kangaroo Bluff, Sandy Bay Point, Taroona, and Tranmere on 8 January 1996. A semilog regression accounts for 89% of the variance in length at age from Kangaroo Bluff, 85% of the variance from Sandy Bay Point, 87% of the variance from Taroona, and 85% of the variance from Tranmere. Differences between sites in the slopes of the regression are significant at $P < 0.0001$.

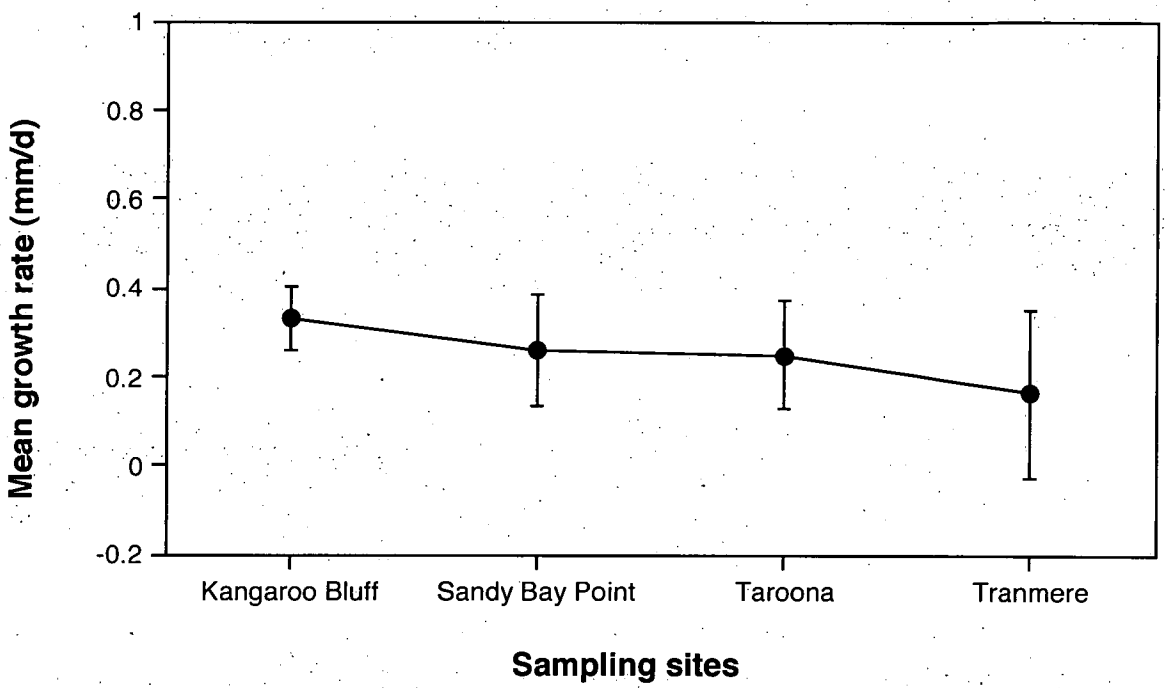

Figure 5.16. Growth rate (mm/d) of larval blennies collected from 4 sites in the Derwent River Estuary on 8.1.96; vertical lines = standard deviation.

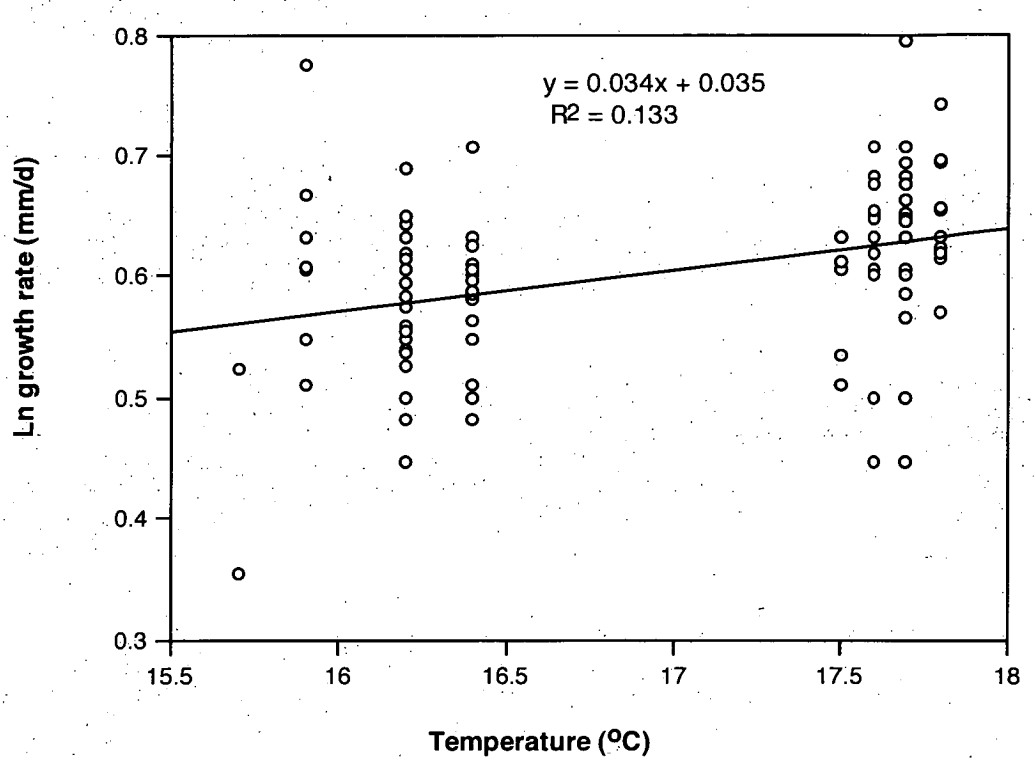

Figure 5.17. Regression of temperature against ln of growth rate (mm/d) of larvae of blennies pooled by 4 sites in Derwent Estuary on 8 January 1996.

5.4 DISCUSSION

Abundance of Larvae

Larval blennies were more abundant in samples collected in 1993-94 than in 1992-93. This variation did not appear to have resulted from differences in any environmental conditions examined in this study as some of these factors were significantly different or different only slightly. Analysis of factors affecting larval abundance between sites indicated that the environmental differences between years were of insufficient magnitude to affect larval abundance.

It follows then, that a factor, or factors, other than tidal patterns, temperature, salinity, wind strength, rainfall, or river discharge affected overall larval abundance resulting in the large difference observed between 1992-93 and 1993-94. Richardson et al. (1980) stated that distribution and abundance of many species of larvae is dependent on the spawning location of adults, timing and intensity of spawning, duration of the pelagic phase (including growth rates and size at transformation) and, especially in coastal regions, current circulatory patterns. The observed difference in abundance of blenny larvae may have been caused by any one of these factors. Among the possibilities tendered by Richardson et al. (1980), variation in spawning is especially likely to have influenced the abundance of Tasmanian Blenny larvae. Spawning/hatching of Tasmanian blennies, back-calculated from otoliths of newly settled juveniles, has been shown to vary between years (Chapter 4) and it is suspected that this is not only affected by a wide range of biological factors but also influenced by physical factors such as shelter, temperature, salinity etc. The biological factors may include food availability and predation. The observed annual variation in larval settlement (Chapter 4) will also affect the year class strength and thus the population size of adults contributing to larval production in any one year.

Within years, the seasonal (weekly) abundance of blenny larvae fluctuated and there appeared to be a peak in abundance approximately every four weeks. The apparent regularity of this cycle suggests physical factors such as tides or moon phase may influence abundance.

Effect of Tides and Moon Phase on Larval Abundance

It is generally believed that behavioural responses of estuarine larvae to tidal flow are important and widespread (Eldridge et al., 1977). In many species, larvae will actively attempt to remain in the same area by moving towards the bottom on ebb tide in order to avoid being flushed out of the estuary (Weinstein et al., 1980). In this study, the abundance of larvae collected during flood tide did not differ from ebb tide sampling and there appeared to be no interaction effect between depth and tide on larval abundance. This suggests that blenny larvae are not retained in the area close to the parents' area as they did not alter their behaviour in response to the tide. Consequently, blennies could be exported out of the estuary away from their parents' area which may affect settlement and subsequent recruitment.

Many commercially important species are dependent on estuaries for nursery areas. Thirteen of 47 species recorded from Botany Bay were believed to spawn within estuaries while only 7 spawned within the Bay itself (SPCC cited by Bruce, 1982). In order for these species to recruit into and remain in the estuary, the larvae or juveniles must avoid being flushed out on the ebbing tide (Bruce, 1982). Bruce (1982) suggested that the direction and velocity of currents are extremely variable with counter flows, eddies and boundary layers of relatively low velocities commonly occurring. The extent to which larvae can take advantage of differential current regimes and thus actively define their position is poorly understood although it appears to be important in estuarine recruitment. Rowe and Epifanio (1994) reported that post-yolksac weakfish *Cynoscion regalis* larvae were significantly more abundant during flood tides, but there was no effect of tidal stage on the abundance of yolk-sac larvae. They suggested that post-yolksac larvae may utilize selective tidal stream transport to effect retention in the estuary.

The apparent absence of any behavioural response of blennies to improve retention in the estuary is surprising and suggests one of two hypotheses: either blennies are not greatly affected by recruitment to non-estuarine areas; or that blennies are otherwise retained in the estuaries, perhaps by circular current motions. Current movements in the Derwent Estuary do indeed tend to be relatively circular, an effect caused by coriolis force interacting with the north-south orientation of the estuary (J. Hunter-pers. comm.).

Neira and Potter (1992) reported that larval gobiids *Favonigobius lateralis*, which spawns in Wilson Inlet, Western Australia, were caught on both ebb and flood tides; those taken on outgoing tides were at the preflexion stage, whereas those caught on incoming tides were almost exclusively at the postflexion stage. Neira and Potter (1992) took this to indicate that *F. lateralis* are flushed out of the system as preflexion larvae and then returned as postflexion larvae on the flood tides. This is similar to the pattern of Tasmanian blennies to some extent as preflexion larvae may be flushed out of the estuary but then return as postflexion larvae during flood tides. This can only remain speculative in Tasmanian blennies as few postflexion larvae have been captured.

Further study, with sampling of postflexion larvae, is clearly required if this issue is to be resolved. As mentioned in chapter 3, postflexion larvae may avoid plankton nets so gear modification may be required. Postflexion larvae may also have diel vertical migratory behaviour which may inhibit their capture by daylight sampling regimes as used in the present study (Miskiewicz, 1987).

Thresher (1984) stated that demersal-spawning fish tend to produce new clutches every two weeks or once a month, usually on a lunar cycle. For example, the Tasmanian clinids *Heteroclinus* spp. appear to produce new broods about every two weeks (Gunn and Thresher, 1991). In this study, the abundance of larvae did not exhibit any evident lunar or semi-lunar periodicity when data were pooled for both years, although there did appear to be periodicity in 1993-94 with more larvae during the new moon period. Critically, the abundance of larvae in relation to the lunar cycle was not consistent for the two years sampled and two explanations are suggested. First, very few larvae were sampled in 1992-93 so any lunar effect may have become blurred by the random variation inherent in small samples. Secondly, spawning activity may have actually varied between the two years. Morgan (1995a) stated that rhythm of larval release in invertebrates such as crabs are innate, heritable, and not easily perturbed by most environmental stimuli such as temperature, which alters the rate of many other physiological process. Although periodicities of larval release cannot be changed, the timing of these rhythms can be phased shifted to match changes in the timing of environmental cycles in animal's environment (Morgan, 1995a). The timing of rhythm of larval release in blennies in 1992-93 may be phased shifted due to changes in the timing of environmental cycles (such as water mass movement, current circular pattern) which slightly differed from 1993-94. Even in the first year

sampled, when no lunar relationship was detected, there appeared to be a 4 week period between peaks which suggests larval peaks (new brood) may follow lunar cycles. However, these peaks did not synchronise with lunar cycles in the second year when larval numbers peaked during the new moon.

The observed strong trend of high abundance of larvae during the new moon may be a mechanism for avoiding predation. Almost all larvae captured were newly hatched larvae (mean = 0.72 ± 1.59 d) which had recently completed or were undergoing yolk sac resorption. During this period, it is likely that avoidance of predators could be paramount to survival given that food capture would not be critical (Johannes, 1978).

The apparent pattern of lunar periodicity in 1993-94 may simply be caused by lunar spawning cycles. However, the same patterns of larval abundance would also be observed if blennies were to spawn throughout the sampling period, but hatching peaked once a month in response to endogenous rhythms of blenny larvae. The spawning cycle (Hsiao and Meier, 1986, 1988, 1989) and semilunar cycles of locomotor activity and otolith ring formation (Meier and Hsiao, 1988 cited by Meier, 1992) persist in *F. grandis* held under constant laboratory conditions indicating that the semilunar/lunar cycle is a basic endogenous cycle.

Effect of Wind on Larval Abundance

Where spawning occurs demersally, larvae may migrate to the surface passively by positive buoyancy, or there may be active migration (Seliverstov, 1974; Bruce, 1982). Once at the surface, distribution of larvae may be affected by surface water movement, such as is generated by wind.

Larval abundance of Tasmanian blennies appeared to be negatively correlated with mean and maximum daily south-easterly wind vector at a lag of 5 d, both when data were pooled for 2 years and for the single year 1993-94. In other analyses, the relationship between larval abundance and wind appeared to be less clear suggesting any effect of wind is relatively weak. No relationship was found in 1992-93 which may be associated with the small sample size.

Although the effect of wind on larval abundance is unclear, results do indicate that the south-easterly wind vector does not concentrate larvae at

the Taroona site, that is, larval abundance in surface waters is not a simple function of surface water movement; larvae were either unaffected by the south-easterly wind vector or they declined in abundance. This suggests that larval surface movement, and thus abundance in certain regions, may be regulated by larval behaviour. Alternatively, larvae may have been concentrated closer towards shore than where sampling occurred, although this is considered unlikely as tows were made only (or approximately) 10 m from shore.

It is interesting to note that the north-westerly wind vector seemed to affect the abundance of larvae causing them to aggregate at the sampling area. This was considered unlikely as the north-westerly wind should drive surface waters to the opposite side of the estuary (east bank; i.e. Tranmere or Ralph Bay Entrance). The observed increase in larval abundance may have been caused by either changes in hatching, or subsequent larval movement.

The effect of north-westerly wind vector was at a lag of 5 d so this physical factor was mainly acting on eggs, rather than hatched larvae. North-westerly wind tends to result in warm water temperature, which should result in eggs hatching earlier. Consequently, hatching may have been contracted resulting in a peak of larval abundance.

The pattern of increased larval abundance with north-westerly wind vector at a lag of 5 d may also have been caused by changes in larval movement. Wind induced currents are strongest in the surface layers and thus a near surface distribution promotes species dispersal (Bruce, 1982). If blennies larvae were mainly distributed at the subsurface, rather than at the surface, north-westerly winds may have caused larvae to be retained at Taroona by cycling water from the surface.

Bailey et al. (1995) reported that walleye pollock larvae *Theragra chalcogramma* in the western Gulf of Alaska were more concentrated in years with calm winds and weak advection than in strong wind years. They suggest wind can have a catastrophic effect on recruitment to the Shelikof Strait pollock population. The observed trend of higher larval abundance of Tasmanian blenny larvae with north-westerly wind may simply be an effect of calmer water. The orientation of the Taroona shore results in low wave action with north-westerly winds, while south-easterly winds are directly towards the shore and result in greater wave action.

Effect of Rainfall on Larval Abundance

Seasonal changes in salinity reflect rainfall patterns (Day, 1981a) so that in the rainy season, estuarine waters become very diluted and brackish water can extend far out to sea (Newell and Barber, 1975). Due to the high abundance of blenny larvae in less saline water in 1992-93 and 1993-94, rainfall was expected to influence abundance of larvae. Unexpectedly, this was not the case as there appeared to be no relationship between the abundance of larvae and rainfall at any reasonable lag of days or weeks.

The relationship between rainfall and salinity in the Derwent Estuary was examined and it appeared that rainfall influenced salinity at a lag of 1 d when data were pooled for all 2 years ($r = -0.25$, $P = 0.05$), however, there appeared to be no significant correlation within separate years ($P > 0.05$). This suggests that rainfall of the magnitude recorded during the study period actually has relatively little effect on the blennies physical environment. Consequently, rainfall may not affect the abundance of larvae as expected.

Effect of River Discharge on Larval Abundance

River discharge has been widely reported to influence the abundance of estuarine fish larvae which are often found in the fronts of plumes (e.g. Mississippi River discharge - Ditty, 1986; Govoni et al., 1989; Grimes and Finucane, 1991; and Connecticut River discharge, American Shad, *Alosa sapidissima* - Crecco and Savoy, 1984). However, river discharge did not appear to exert a strong influence on the abundance of blenny larvae in the Derwent River Estuary. Discharge was recorded at Meadow Bank (Fig. 4.1) which is far from the sampling site so relationships may have become blurred. The apparent absence of an effect of river discharge is not unlikely as larval sampling was conducted during the dry summer period so discharge was relatively small, and there appeared to be little effect on salinity.

The Effect of Temperature and Salinity on the Abundance of Larvae

It is unlikely that variation in temperature and salinity could account for interannual differences in abundance of blenny larvae as they were very similar for both years. However, short term or weekly variation did appear

to be affected by these factors as abundance of larvae was positively related to water temperature and negatively related to water salinity when data were pooled for two years. There also appeared to be an interaction effect of temperature and salinity on the abundance of larvae. These results imply that blenny larvae were distributed in warm water of lower salinity. This pattern became less clear within years although strong trends remained; it is considered that the low sample size in 1992-93 may have introduced high error.

These results are similar to those of Laprise and Pepin (1995) who reported that high abundances of total ichthyoplankton species in Conception Bay, Newfoundland, Canada usually corresponded to the periods of warmest waters. They proposed that temperature is the principal factor controlling spatio-temporal occurrence of fish eggs and larvae in the Bay. This agrees with Brett's statement (1956) that "temperature acts as a directive factor resulting in the congregation of fish within given thermal ranges or movements to new environmental conditions". It appears that in many species there is an optimum range of temperatures, rather than a precise optimal temperature. Research conducted in the Hopkins River estuary, Victoria found peaks in fish larval abundance occurred at several temperatures well before and after the attainment of maximum water temperature (Newton, 1996).

The response of blenny larvae to water temperature and salinity is typical for an estuarine species although this pattern does not always occur. Castro and Cowen (1991) reported that the duration of peak spawning season in bay anchovies *Anchoa mitchilli* in the Great South Bay, New York was not correlated with salinity or temperature but that other physical factors over-rode these effects.

Intensive Larval Fish Sampling

Intensive larval fish sampling confirmed that blenny larvae were primarily distributed in less saline water of higher temperature. Locke and Courtenay (1995) investigated the effects of environmental factors on ichthyoplankton communities in the Miramichi estuary, Gulf of St Lawrence and found that salinity was the most useful predictor of larval distribution in the estuary. They suggested that salinity is likely to be the overriding determinant of ichthyoplankton distribution and that other environmental features, including those related to water transparency, are modifiers of distributions within salinity ranges. Hinckley et al. (1991) demonstrated

that current movement affects salinity, and thus modifies the spatial effects of salinity on pollock larvae in downstream coastal nursery areas. In blennies, current and circulation pattern or water mass movement within the Derwent estuary may affect salinity and thus modified the spatial effects of salinity on distribution of blenny larvae. However, the clue that why blenny larvae prefer less saline is not clear, further study in laboratory experiment on effect of salinity on development of larvae and physiology of larvae is required.

The occurrence of high densities of blenny larvae in low or intermediate salinity may be a strategy to enhance growth and survival. Iwatsuki et al. (1989) showed that blennioid larvae were transported offshore from the coastal water whilst the copepods and nauplii originated from the offshore water. In this study, although no data were collected on the prey items present in different water masses, the gut contents of blenny larvae were not different between sites. This indicated that there was no food limitation between the different water mass. However, the prey items that I did not identify to species level may be a clue to account for the difference in larval abundance in different water mass. Newton (1996) found that the spawning of black bream (*Acanthopagrus butcheri*) and anchovies (*Engraulis australis*) in Hopkins River estuary, Victoria was clearly related to physical conditions, such as salinity and water temperature. Newton (1996) also found that spawning of both species occurred at times of high concentrations of potential prey organisms for their larvae. She suggested that adults of all the above fish species appear to have evolved spawning strategies that are adapted to the average hydrological and biological conditions in the estuary that would lead to the enhanced survival of their larvae. In blennies, although there was no data of adult in relation to hydrological and biological conditions in this study, it is possible that blenny adult may have spawning strategy adapted to the average hydrological conditions; e.g. to warm and less saline water, in the Derwent River estuary that enhanced blenny larval distribution and survival.

Length-frequency analysis indicated that larvae caught at Sandy Bay Point were smaller than those at Kangaroo Bluff and Tranmere. There were also differences in size of larvae between nearshore and offshore stations with offshore larvae, generally postflexion, tending to be larger than those collected nearshore ($P < 0.05$). It suggested that older larvae can be maintained further offshore on the east bank of the Derwent River. This may be caused by the higher proportion of newly hatched larvae in

nearshore samples; hatching sites may be nearshore and larvae are subsequently dispersed towards the offshore stations.

The overall patterns of larval movement remains unclear as most larvae were captured early in development. Only a few postflexion larvae were caught from all 4 sites so further sampling is required if the overall patterns of larval movement are to be understood.

Growth rate

From the previous discussion, it appears unlikely that the observed large interannual variation in larval abundance can be attributed to a simple effect of one physical factor. Temperature appeared to vary little between years although this is widely accepted to be an important climatic factor influencing the growth and survival of larvae (Blaxter 1969; Leiby, 1984; Allen and Barker, 1990). For example Bailey et al. (1995) reported annual differences in growth of walleye pollock larvae due to poor feeding conditions and low temperature. Temperature has also been shown to be extremely important on Tasmanian fish populations with interannual variation in populations resulting from changes in water temperature (Harris et al., 1988). Growth rate of blenny larvae was assessed by otolith analysis which is known to be related to water temperature (Thomas,1986).

Temperature appeared to have little role in the interannual variations observed in the present study. Other physical factors may have combined or interacted to cause differences in survival between years and these can also be expected to influence growth. Also, growth rate will affect the duration of larval development; if larvae were to grow more slowly the planktonic larval population should be larger as settlement will be delayed.

Growth rate of larvae in 1993-94 (0.35 mm/d) was significantly faster than in 1992-93 (0.23 mm/d) when larvae were less abundant. The significantly slower growth and lower abundance in 1992-93 suggest environmental conditions were poor for survival. Also, the more rapid growth in 1993-94 suggests density-dependent inhibition of growth did not occur in these larvae. Although there was no information of food availability, density-dependent growth, from competition for food often leads to prolonged stage duration, increased predation mortality, and subsequent poor recruitment (Ricker and Foerster, 1948; Shepherd and Cushing, 1980).

Growth rate of larvae from intensive sampling was also investigated and it appeared that the growth rate of larvae varied between the different water masses. Larvae grew most rapidly at Kangaroo Bluff, the site with highest abundance which again suggests density dependant suppression of growth was not evident. The slowest growth occurred at Tranmere which had abundance lower than at Kangaroo Bluff, although it was still relatively high.

Further study on condition of blenny larvae such as RNA/DNA ratio in relation to growth rate may explain this evidence. Larvae in good condition tend to have a higher RNA/DNA ratio than those in poorer condition (e.g. Robinson and Ware, 1988; Clemmensen, 1993). Suthers et al. (1996) utilised relative RNA content as a measure of condition in larval and juvenile fish. They found that residuals derived from the regression of RNA on SL of Australian bass (*Macquaria novemaculeata*) showed significant difference between four different feeding regimes. They also found that a residual-based index (RNA on dry weight) of juvenile monacanthids (*Paramonacanthus otisensis*) showed parallel fluctuations at all sites; they were positively correlated with water temperature.

Predation

Predation is now thought to be a major factor influencing recruitment variability (Hunter, 1981). It may be particularly important in estuaries as the relatively high abundance of food reduces the likely occurrence of starvation related mortality (Houde and Lovdal, 1985; Mackenzie and Leggett, 1991). Larval fish predators are very diverse and include euphausiids, copepods, crustacea, ctenophores, fish and birds (Theilacker and Lasker, 1974). Jenkins (1986) suggests that gelatinous planktons are the most important predators of larval fish. Predation will confound observations of the effects of other factors such as growth rates. There is also feedback loops of physical factors on predation; for example, growth rates can significantly reduce the time that younger stages are exposed to high predation rates (Bailey and Houde, 1989).

The effects of predation on larval abundance of blennies was not assessed and is a notoriously difficult factor to quantify. However it is worth noting that predation may have influenced larval abundance and could have been a factor in some of the unexpected patterns of blenny larval abundance.

Photoperiod

The mechanisms by which larval fishes are recruited to and concentrated in estuaries are poorly understood (Eldridge et al., 1977). The larval phase is the stage mainly affected by the current, but not always with the same result as currents may have both positive and negative influence during the larval life of fish and invertebrates (Pearce and Phillips, 1988, 1994; Caputi et al., 1995, 1996; Joll and Caputi, 1995). However, it is generally believed that behavioural responses to photoperiod are important as vertical migration and thus tidal transport can be affected.

Hydrodynamic forces can aid transport of larvae into estuaries, but behavioural mechanisms are important in maintaining distribution. For example, larval fish and larval invertebrates appear to regulate their dispersal by vertical migration (Cronin and Forward, 1979; Weinstein, 1980; Fortier and Leggett, 1982). Aggregating near the bottom of the estuary, sometimes by epibenthic schooling, larvae take advantage of the residual landward flow and can effectively avoid being flushed out of the estuary (Cronin and Forward, 1979; Steffe, 1991 cited by Sutton, 1992). The ability to do so effectively increases with age as the functional responses become more developed (Roper, 1986; Laprise and Dodson, 1989).

The behavioural response of blenny larvae to regulate dispersal appears to be fairly slight, if present, as discussed in relation to tides. However changes in lighting, of either photoperiod or intensity, was not assessed and may have influenced larval movement. Light intensity is widely recognised to be important in determining larval movement (Cronin and Forward, 1979) which may have influenced sampling. Rapid changes in light intensity can also produce strong migration responses, different to those which occur at constant intensities (Gardner, 1996). This may result in different patterns of larval distribution on days where light intensity is repeatedly varying due to cloud movement compared with days where light is relatively constant. Thus light intensity measurements should be included in future studies evaluating effects of physical factors on larval abundance.

In conclusion the main findings of this study were:

- Salinity appeared to be a useful predictor of larval blenny abundance. Temperature seemed to relate to larval abundance.

- Peaks of larval abundance appeared to be related to north-easterly wind vectors and appeared to be related to lunar phase with highest abundance on new moon.
- Other factors such as river discharge and rainfall did not appear to affect the abundance of larvae. The lack of consistency between years could indicate adaptation to an unstable natural environment.

CHAPTER 6

GENERAL DISCUSSION

Effect of Biological Factor (Chlorophyll-a concentration) on Hatching, Larval Abundance, and Settlement Variability

Chlorophyll-a concentration did not appear to affect hatching or larval abundance in this study. These contrast to findings of Cushing (1967) who reported that variations in the spawning times of herring (*Clupea harengus* L.) populations in the northeast Atlantic were linked to variations in production. Hatching and larval release of blennies may not correspond with the availability of suitable food because of variations in the timing of seasonal plankton blooms. Other factors may override this. Sinclair (1988) cited many examples in which fish spawning times and larval survival apparently showed no relationship to the annual phytoplankton production cycle which suggests that physical factors predominate over food chain processes in the control of population biology. Blennies are estuarine species, so physical factors have much potential to disperse and affect spatial integrity therefore primary production may be less important in spawning/hatching.

There was no consistent relationship between chlorophyll-a concentration and hatching and larval abundance between two years (chapter 3). This suggests that there is no direct and simple mechanism linking the two variables. This contrasts to the idea of Crisp (1954) who thought that the breeding cycles of fish are regulated so that their larvae hatch at a time favourable to finding food, a strategy that should help these animals survive a critical period of their lives. In the current study, newly hatched blennies may hatch and release larvae at time that did not correspond with the availability of primary production. However, It is conceivable that hatching of blennies may be influenced by other variables, such as moon phase or photoperiod.

The absence of an effect of chlorophyll-a concentration on settlement contrasts to a recent investigation of Thresher et al. (1989) on the settlement of larval clinids *Heteroclinus* spp. in the Derwent Estuary in Tasmania. They found that episodic settlements were invariably preceded

by brief, irregularly occurring pulses in phytoplankton production. The results of the present study appear to be inconsistent with the ideas of Cushing (1972, 1975), who suggested that the timing of peak spawning activity of fish and the spring phytoplankton bloom could fluctuate by several weeks from year to year. Cushing (1972) suggested that the reproduction in an area should interact with the mean seasonal pattern of phytoplankton production. The relationship between growth rate of larvae and water chlorophyll indices has been used to explain the effect of phytoplankton production pulses on the survival of larvae and thus settlement (Munk, 1993). Munk (1993) reported a positive correlation between growth rate of larval sprat *Sprattus sprattus* in the eastern North Sea off the west coast of Denmark, and chlorophyll content of water, except at high levels (> 110 mg/m^2) of chlorophyll where growth rate may become depressed. In blennies, if food availability does affect survival then settlement should correlate with chlorophyll-a (Thresher et al., 1989). However, no such clear relationship between phytoplankton production (chlorophyll-a concentration) and subsequent settlement occurred in the present study which suggests that food may be not limiting factor in the Derwent River Estuary (as percent of fish with food in stomach in 1992-93 was similar to 1993-94) and other environmental factors may be more critical in influencing blenny settlement.

Effect of Physical Factors on Variation in Hatching, Larval Abundance, and Settlement

As the production pulse did not explain peaks in hatching, larval abundance, and settlement variability, it was assumed that some physical factors had effect on those.

Temperature and Salinity Effect

•*Effect of temperature and salinity on larval abundance*

Fluctuations in temperature and salinity did not appear to result in the interannual differences in larval abundance although they appeared to affect the seasonal pattern of the abundance of larvae.

Water temperature is frequently observed to affect survival in finfish larvae. For example, striped bass (*Morone saxatilis*) spawning in the Potomac River, Chesapeake Bay during 1987 produced approximately 60% of the annual spawn prior to 20 April, but all the eggs or larvae were lost as a result of lethal low water temperatures following heavy rainfall (Houde et al., 1988; Houde, 1989). Similarly, Ahlstrom (1965) recorded that lethal

high temperatures eliminated the entire spawning of the northern component of the Pacific sardine population off western USA in 1953.

Likewise, many estuarine fish, e.g. gobies and clupeids, increase in abundance after warming of the water in spring and summer (Jenkins, 1986; Miskiewicz, 1987; Steffe, 1991 cited by Sutton, 1992; Sutton, 1992). This has been attributed to more physiologically suitable temperatures for larval growth and improved food availability (Jenkins, 1986; Miskiewicz, 1987; Steffe, 1991 cited by Sutton, 1992).

Of the environmental factors assessed in this study, only salinity and temperature appeared to have a large effect on larval abundance. Peaks of larvae during the sampling period in 1992-93 and 1993-94 appeared to correspond to increases in temperature and declines in salinity, especially in 1993-94 (chapter 5). The relationship of larval abundance with these two factors was positive with temperature and negative with salinity (chapter 5). Intensive larval sampling in 1996 also demonstrated increased abundance of larvae in warm and less saline water (chapter 5). These results are consistent with a recent laboratory study of temperature tolerances of Tasmanian blenny eggs and larvae by Mills (1994). Mills (1994) reported that survival of the blenny larvae to flexion was lowest at 15°C, intermediate at 18°C, and highest at 21°C and 24°C. These results appear surprising, as the lower temperatures (15°C and 18°C) correspond to those that larvae are routinely exposed to in nature and yet resulted in poor growth and survival. Water temperatures in the field during sampling for the submitted study were often only slightly higher than 12°C around the time of incubation so it is possible that hatching rate was affected. If the results of Mills (1994) are extrapolated to the wild, few larvae could survive at natural water temperatures. Conversely, the results are broadly consistent with the results of the present study, in which I found larvae were most abundant in warm water. Perhaps this is due to increased survival under more physiologically suitable conditions.

Of the environmental factors investigated, salinity was the most useful predictor of larval blennies distribution in the Derwent River Estuary. Sutcliffe et al. (1983) and Myers et al. (1993) observed a correlation between salinity and recruitment of larvae in Atlantic Cod (*Gadus morhua*) in the Newfoundland region. Sutcliffe et al. (1983) suggested that the link was through the food chain, with high salinity corresponding to high nutrients, high primary and secondary production, and greater food availability for cod larvae. However, Myers et al. (1993) considered that

this hypothesis was not consistent with the limited data available. Myers et al. (1993) suggested an alternative hypothesis where salinity appeared to be related to larval abundance through advection-related processes.

The food chain hypothesis, as proposed by Sutcliffe et al. (1983), is less likely to account for the preference of blenny larvae for low salinity water in this study. No difference was found in the percentage of food in the stomachs of larvae (gut fullness) sampled in different water masses (salinities) (Chamchang, unpublished data). However, it should be noted that I did not analyse the gut contents to species level; prey diversity and composition could be important factors affecting larval abundance (e.g. Castro and Cowen, 1991).

The second hypothesis of larval advection or onshore water mass movement (Myers et al., 1993) is more likely to be responsible for the link between blenny larval abundance and salinity. Estuarine organisms tend to be distributed along salinity gradients with seasonal changes in species composition reflected in salinity and distance from the mouth of the estuary (Longeragan and Potter, 1990). Locke and Courtenay (1995) found that higher larval abundances of Atlantic tomcod (*Microgadus tomcod*) and rainbow smelt (*Osmerus mordax*) were associated with more saline water. They suggested that salinity (together with longitudinal position in the estuary) was the most consistently useful predictor of the location of larvae in the estuary.

•*Effect of temperature and salinity on settlement*

The effect of temperature and salinity on settlement was only assessed in 1995-96 to test the hypothesis that the settlement of blennies is determined by water mass with high temperature and low salinity. Of the environmental factors assessed in 1995-96 for their effect on settlement, only salinity appeared to have a large effect (chapter 4). The number of newly settled juveniles appeared to be greatest in areas with high salinity. This suggests that the salinity preferences of newly settled blennies differed from larvae sampled in plankton tows (as mentioned earlier). This indicates that of the environmental factors investigated, salinity was the most useful predictor of larval abundance and newly settled juvenile blennies distribution in the Derwent River Estuary.

High salinity water may provide more prey items for newly settled juveniles in the Derwent Estuary. The inshore region of the east coast of Tasmania, about 35 km to the east of mouth of the Derwent River Estuary and Storm

Bay areas is influenced by subantarctic water in October, November, and December (Wood, 1954; Nyan Taw unpublished data cited by Nyan Taw and Ritz, 1979) with an oceanic water influence for some considerable distance up the river along the west bank (where Taroona sampling site was located). This water is cool and rich in nutrients. This water mass may bring food such as planktonic dinoflagellates and nutrients to the area where high settlement occurred such as Taroona.

As speculated later in discussion of tidal effects on larval abundance, postflexion larvae may develop outside the estuary and then pre-settlement stage larvae may return to settle during flood tides. This implies that the preference of newly settled juvenile in high salinity may appear to exist as settling larvae will be transported in high salinity water. However, it is important to remember that these pre-settlement stage larvae may also actively swim and select for suitable settlement sites (Leis et al, 1996). Consequently, habitat selection by newly settled juveniles may be important as discussed later in this chapter.

Tidal Effect

•Effect of tidal cycle on hatching

The physical environment affecting fish in the inshore subtidal region is highly regulated by the tidal cycle, and hatching is often affected. Hatching of damselfishes *Pomacentrus flavicauda* appear to follow cycles that are correlated with tidal states, with maximum hatching occurring on days when spring high tides fall near sunset (Doherty, 1983). He suggested that hatching at this time facilitated transport of the larvae off the reef by the ebbing tides. In this study, interannual and seasonal variations in hatching of blennies did not appear to be affected by tidal range (chapter 4). Blennies may exhibit behaviour patterns of hatching asynchronized with the tidal cycle.

•Effect of tidal cycle on larval abundance

Adult fish in estuaries synchronise their behaviour with the tides either to achieve transport or to prevent displacement. The principal goal of those species that use tidal currents for transport is to obtain access to feeding areas (Miller and Dunn, 1980) or spawning grounds. Creutzberg et al. (1978) suggested that North sea plaice larvae *Pleuronectes platessa* might use tidal currents for their transport towards the tidal flats in estuarine nursery areas, where food conditions are thought to cause plaice larvae to settle. In this study, there appeared to be no difference in the abundance of larvae collected during flood tide and ebb tide sampling (chapter 5).

Also there appeared to be no interaction effect between depth and tide on larval abundance which suggests that blenny larvae did not alter their behaviour in response to tide. However both depths sampled were relatively close to the surface (below surface and at 5-10 m depth) so larvae may have descended deeper, thus clouding trends of tidal effects.

There was no behavioural response to tidal movement by blenny larvae (newly hatched larvae) with larvae generally remaining at the surface. This is consistent with the findings of Cook (1986) and West (1988) who reported that newly hatched blennies were active swimmers and, being positively phototactic, they kept close to the water surface. The newly hatched larvae of demersal eggs are usually strong swimmers with pigmented eyes, well developed fin precursors, and a small yolk sac (Thresher, 1984). Miller (1988) suggested that the vertical movements of fish larvae in estuaries could be partially explained by differential buoyancy in water layers of different salinity. He also suggested that increased density of well fed larvae could cause them to sink and accumulate near the bottom and that the spreading out and decrease of velocity of water masses entering lagoons is likely to cause net retention of larvae within the lagoon. In this context, Bergman et al. (1989) demonstrated that larval plaice are transported passively into the Wadden Sea by tidal currents and sink when current velocities decrease at high tide in much the same way as suspended inert material. If the larvae do not feed and assume a pelagic existence, they are likely to be transported back out of the area by the ebb currents. The apparent lack of a response of blenny larvae to tidal movement may reflect low food consumption causing larvae to remain positively buoyant.

Many studies in tidal inlets and estuaries have documented higher concentration of larvae in a variety of fish species on flood tides (especially at night) than on ebb tides, possibly suggesting selective use of tidal currents to retain larvae (e.g. in plaice by Creutzberg, 1978; Creutzberg, et al., 1978; in flounder (*Platichthys* sp.) by Tsuruta, 1978; in English sole (*Parophorys vetulus*) by Boehlert and Mundy, 1987). In this study, there was no difference in overall abundance of larvae during flood and ebb tides in surface tows which indicated that there was no selective behaviour to utilise tidal stream transport. This may lead to loss of larvae due to flushing out of the estuary with variable settlement between years. Most blenny larvae caught in this study were newly hatched which are less active swimmers and as discussed earlier, they tended to concentrate near the surface. Consequently, it appears that they were passively distributed

and therefore the abundance of larvae during flood and ebb tides was similar.

Cook (1986) reported that there was no evidence of any tidal pattern of feeding in adults of Tasmanian blennies, although this often occurs in littoral fish as they utilise intertidal organisms in their diet. It may be that blennies are particularly unresponsive to tidal movement as they are territorial so that blennies did not move up to the high tide. Although some form of modification of larval behaviour over the tidal cycle has been frequently reported, knowledge of its general applicability is vague. Lyczkowski-Schultz et al. (1990) found no consistent tidal periodicity in larval distribution and abundance that facilitated movement into, or retention within, Mississippi Sound, and Boehlert and Mundy (1987) were unable to provide an explanation for larval transport into Yaquina Bay by tidal phenomena.

Although there appeared to be no effect of tide on total larval abundance, most preflexion stage of blennies were captured during ebb tide. This suggests that these preflexion stages may be exported out of the estuary by tidal movement, develop to postflexion stage outside the estuary, and then return to the estuary to settle. However, there were few postflexion stage larvae caught and no other research has been conducted on the distribution and type of marine habitat occupied by these larval stages.

The few postflexion larvae captured were from Kangaroo Bluff and Tranmere in offshore samples (100 m offshore). These fish were captured during intensive larval fish sampling over one day during ebb tide and the few larvae captured make statistical analysis impossible. However, two hypotheses are suggested to explain larval dispersal; first, postflexion larvae may be dispersed away from the parent's area by currents and then actively swim or are actively driven onshore to settle into suitable tide pools such as at Taroona (Fig. 6.1).

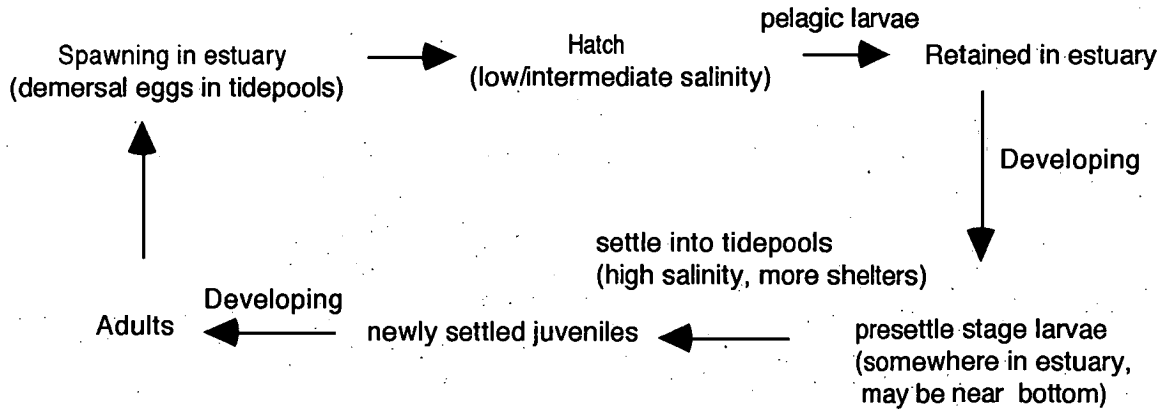

Figure 6.1. Diagram of possible life cycle of blennies within Derwent Estuary (hypothesis 1)

This pattern is similar to that reported by Sponaugle and Cowen (1996) who found that the spatial pattern of larval supply of *Stegastes partitus* and *Acanthurus bahianus* varied between species, suggesting that larval supply was not simply the result of passive transport. They also found that the density of juvenile *A. bahianus* were directly opposite to patterns of larval supply which suggests that post-settlement processes, such as habitat selection, may be more influential on patterns of recruitment.

In the second hypothesis, postflexion larvae may develop somewhere outside the estuary and return to the estuary to settle. As few postflexion larvae have been captured, this can only remain speculative (Fig. 6.2).

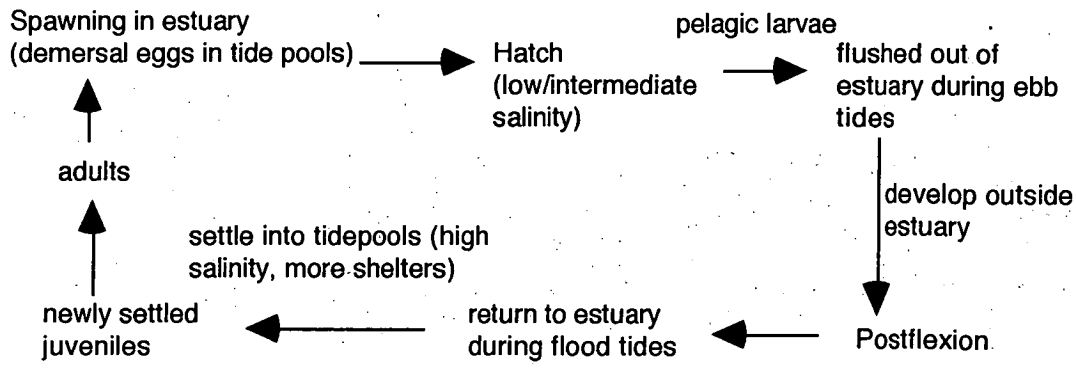

Figure 6.2. Diagram of possible life cycle of blennies within and outside Derwent Estuary (hypothesis 2)

Ebb and flood tides are generally important in dispersing larvae released in estuaries and nearshore areas and also in returning them for settlement (Young, 1995). By returning to the estuary during flood tides, larvae may be affected by coastal ocean water with high salinity and lower temperature. In the Derwent Estuary, the coastal ocean drainage generally flows below less saline water on the west bank (Thomson and Godfrey, 1985) where the Taroona sampling site was situated. Highest settlement occurred at the Taroona site which may have resulted from transport of pre-settlement larvae by coastal oceanic water to this region. However it is important to remember that these larvae may also actively swim and select for suitable settlement sites (Leis et al., 1996).

Further investigation on location of postflexion larvae of blennies is required to test these hypotheses. Sampling at night during flood tides and developing appropriate gear to catch pre-settlement stage of blennies is critical.

•*Effect of tidal cycle on settlement*

The results in chapter 4 showed that there appeared to be no consistent correlations between tidal range and back-calculated settlement over varying lags between years. No apparent tidal cycle effect on settlement in this study is surprising as most inshore estuarine species exhibit some form of tidal influence. Thorrold et al. (1994b) suggested that most settlement-stage juveniles of inshore species utilise flood tides to move onshore. Doherty and McIlwain (1996) captured most pre-settlement fish on nocturnal flood tides, when rising water first spilled into the lagoon at One Tree Reef. In blennies, behaviour of newly settled juveniles may play a role in their movement into tide pools. Pre-settlement stage larvae may actively swim to tide pools and may not rely on flood tides to drive them onshore.

I conclude that there is no apparent selective tidal stream transport of early developmental stage blennies and that behaviour of later stage blennies may play a role in movement back to settlement sites.

Lunar Phase Effect

•*Effect of lunar phase on hatching*

In the present study, no significant relationship was observed between lunar phase and back-calculated hatching dates based on ages of settled juveniles when data were pooled across 4 years (chapter 4). In individual years, a significant effect of lunar phase on hatching dates emerged only in

1995-96 (chapter 4). The lack of consistency between years may be due to small sample size of newly settled juveniles in 1992-93 and 1993-94. Hatching dates of blennies appeared to exhibit lunar cycle, although there was lack of consistency between years. There was a strong trend of greatest hatch on the full moon in 1994-95 and 1995-96 which suggests that blennies tend to hatch once per month. This conforms with Thresher's suggestion (1984) that demersal-spawning fish tend to produce new clutches either every two weeks or monthly, usually on a lunar cycle. Larval survival may be enhanced by the observed pattern of hatching on the full moon as newly hatched larvae are likely to be phototaxic. This is consistent with the findings of Cook (1986) and West (1988) who reported that newly hatched blennies were active swimmers and, being positively phototactic, they kept close to the water surface. This is also in agreement with one of the hypotheses reviewed by Thresher (1984), that hatch on the night of the full moon results in photopositive larvae swimming toward the brightly illuminated surface and away from the predator-filled reef. Under natural conditions, movement toward light of newly hatched larvae would result in movement toward the surface, increasing dispersal away from the rocky reef (Leis, 1991a). Blennies may utilise this mechanism and also endogenous rhythms and behavioural activities to disperse their larvae from rock pools on full moon period.

•*Effect of lunar phase on larval abundance*

The moon's influence on living organisms is most marked in the sea because of the moon's effect on the tides (Gibson, 1978). Highly significant but independent effects of moon and tidal state in marine species point at the important of favourable currents to successful larval recruitment (McFarland et al., 1985). Most organisms studied to date exhibit some aspects of endogenously rhythmic physiological activity, and in most there are some aspects of their physiology that are either synchronized by external cues (Zeitgebers), or entrained by external factors (e.g., time of feeding, tides, onset of photoperiod, etc.), that is, exogenous rhythms. Lunar cycles may be maintained by endogenous rhythms: the spawning cycle (Hsiao and Meier, 1986, 1988, 1989) and semilunar cycles of locomotor activity and otolith ring formation (Meier and Hsiao, 1988 cited by Meier, 1992) persist in the killifish, *Fundulus grandis* held under constant laboratory conditions indicating that the semilunar/lunar cycle is maintained as an endogenous cycle.

An example of a different type of lunar-related migration is that of the white sucker, *Catostomus commersoni*, reported by Kavaliers (1982). He

provided evidence of an endogenous lunar rhythm in the absolute maxima and minima temperatures selected by the animal during its diel rhythm of temperature selection; significantly higher temperatures are selected at the times of the new moon than at the times of the full moon. Kavaliers (1982) proposes that this lunar rhythm might enable the suckers to feed in shallow, warm waters at the times of the new moon, when the risk of predation from visual predators is reduced, and may be related to the lunar-related shifts in spectral sensitivity reported for *Poecilia reticulata* by Lang (1967).

In the present study, lunar rhythms in larval abundance were not consistent between years due to low larval supply in 1992-93, although there was a significant lunar effect on abundance in 1993-94, with greatest number of larvae occurring on the new moon period. The mean water temperature in 1993-94 was 0.4ºC higher than 1992-93 and each peak of larval abundance in 1993-94 appeared to be consistent with higher temperature (chapter 5). Although the effect of interaction between lunar phase and temperature was not significant ($P = 0.1$ when data were pooled for 2 years and $P = 0.068$ for 1993-94), there appeared to be a strong trend in larval abundance with greatest number occurring on higher temperature on the new moon period. This implies that blenny larvae may select for higher temperature at the time of the new moon period to minimize predation as suggested by Leatherland et al. (1992). However these data were collected over a short period and further study is required to test this hypothesis as there were not a wide range of temperatures on new moon periods. The gulf killifish, *Fundulus grandis*, undergoes annual and semilunar cycles of reproductive, metabolic and behavioural activities. The annual cycle is primarily a consequence of seasonal changes in water temperature acting through an endogenous cycle of seasonal changes in response to temperature (seasonality). Both ambient temperature and seasonality are thought to alter the phases of circadian neuroendocrine rhythms (Meier, 1992).

The behaviour of pre-settlement blenny larvae may play a role in the apparent lack of consistency of lunar periodicity between years. Thorrold et al. (1994a) suggested that lunar periodicity in the supply of taxa such as leptocephali in the Bahamas has a considerable behavioural component. They argued that the extended larval durations of most leptocephali should act to largely decouple spawning and recruitment. Given that the lunar patterns were not driven by similar periodicity in water movements (Thorrold et al., 1994a), it was concluded that larvae must be selectively

and actively, moving onshore over new moon periods. Thorrold et al. (1994c) found significant interannual variability in the vertical and horizontal distributions of settlement-stage fishes which suggests that behaviour may play a major role in determining larval supply in shorefishes.

•Effect of lunar rhythms on settlement

Settlement of blennies did not have significant periodicity in relation to lunar phase in this study (chapter 4) although abundance of larval blennies appeared to be greatest on new moons (chapter 5). If blennies have fixed larval duration (mean = 46 days approximately, chapter 3), their settlements should be greatest around the full moon period. In the present study, there appeared to be a strong trend of settlement of blennies on waxing half moon. This discrepancy may have been caused by variation in larval duration which ranged from 36 to 69 days and differed between years ($P < 0.0001$). Consequently, there appeared to be no significant trend of lunar periodicity to settlement. This supports the statement of Robertson et al. (1990) who suggested that high correlation between lunar cycle and settlement occurs with lunar spawning only when the larval duration is fixed.

Wind Effect

•Effect of wind on hatching

In the present study, there appeared to be no effect of wind strength on interannual and seasonal differences in back-calculated hatching of blennies. The major sampling site in this study (Taroona) is on the southwestern of the Derwent Estuary and is fully exposed to south-easterly wind which wind generated turbulence was not great enough to influence survival.

•Effect of wind on larval abundance

Wind induced surface currents are important in the transportation of larvae and thus may affect recruitment, particularly in those species with separate well defined spawning and nursery areas (Cushing, 1975; Bruce, 1982).

In the present study, results indicate that the south-easterly wind vector does not concentrate larvae at the Taroona site on the west bank of the Derwent River Estuary. There were negative correlations between south-easterly wind vector at lags of up to 5 d and the abundance of larvae when data were pooled for 2 years. There was also a significant negative

correlation between larval abundance and south-easterly wind vector at a lag of 5 d in 1993-94 although no relationship was found in 1992-93 which may be a statistical effect of the small sample size and thus the increased error (chapter 5). The small effect of the south-easterly wind vector on abundance of larvae suggests that larval surface movement may be regulated by larval behaviour rather than simply passive transport.

The observed trend of higher larval abundance of Tasmanian blenny with north-westerly wind may simply be an effect of calmer water. The orientation of the Taroona shore results in low wave action with north-westerly winds, while south-easterly winds are directly towards the shore and result in greater wave action (see map in chapter 5, Fig. 5.1). North-westerly wind in the Derwent Estuary tends to result in low wave action with warm water temperature and rainfall which results in lower salinity. This suggests that the observed negative correlation of larval abundance with south-easterly wind vector at 5 d lag may be an effect of calmer, warmer water of lower salinity. This is supported by the intensive larval fish sampling programme that found a greater abundance of larvae in warm and less saline water (chapter 5). These results are similar to those of Bailey et al. (1995) who found that walleye pollock larvae *Theragra chalcogramma* in the western Gulf of Alaska were more concentrated in years with calm winds and weak advection than in strong wind years. They suggest that wind can have a catastrophic effect on recruitment to the Shelikof Strait pollock population.

•*Effect of wind on settlement*

Settlement appeared to be unaffected by wind strength. As mentioned earlier in relation to larval abundance, the slight effect of the south-easterly wind vector on subsequent settlement suggests that larval surface movement may be regulated by larval behaviour rather than simply passive transport.

Larvae of most marine animals disperse from parental populations and may be advected many kilometers with swimming speeds two to three orders of magnitude less than velocities of surrounding currents. Therefore, many larvae are incapable of swimming horizontally to reach distant settlement sites (Morgan, 1995b). Although even strongly swimming larvae, such as decapod and fish larvae are unable to reach appropriate areas to settle (Efford, 1970; Hare and Cowen, 1993), considerable evidence suggests that mortality from advection is minimized by larval behaviour. Even the weakest swimming larvae may regulate

horizontal transport by vertically migrating in response to predictable hydrodynamic features, such as stratified water masses and tidal currents (Leis, 1991b; Gibson, 1992; Shank, 1995; Young, 1995). In the St. Lawrence River, larval smelt (*Osmerus mordax*) show ontogenetic differences in behaviour which is believed to influence dispersal (Gibson, 1992). Young larvae concentrate near the surface on flood tides and are subsequently dispersed by passive sinking as the flood tide reduces in speed. The amplitude of the vertical migration of older larvae is greater than the younger stages and they become concentrated on both flood and ebb. They thereby use the currents more efficiently than the younger stages (Gibson, 1992). In blennies, larval behaviour may regulate horizontal transport induced by north-easterly wind vector to avoid advection to the eastern shore.

Shenker et al. (1993) hypothesized that a number of taxa were utilizing wind-driven currents in the surface layers to transport them into nearshore waters. Thorrold et al. (1994c) found that most settlement stage fishes were concentrated in surface water although this trend was less pronounced for several taxa in the second year of sampling. They found that a higher proportion of larvae of leptocephali, bothids and labrids moving onshore were taken in the subsurface nets in the second year. Their explanation for this annual variation related to the influence of wind-driven surface currents on larval distributions. The majority of fishes in the first year of sampling were collected during pulses in replenishment that coincided with strong storm events. Larvae appeared to be transported onshore by wind-driven currents, and were concentrated in the surface water where current velocities were highest (LeFevre and Bourget, 1991). In the second year, pulses were not associated with strong onshore wind events (Thorrold et al, 1994a), although recruitment of several taxa were in fact higher in the second year. Thorrold et al (1994c) suspected that directed swimming by the larvae may play some role in transport and larvae are capable of using a number of interacting mechanisms to move from the larval planktonic environment to suitable juvenile habitats. A similarly complex pattern may be utilised by Tasmanian blennies to regulate transport to favourable sites for settlement, given that there was only low correlation with factors analysed.

Rainfall and River Discharge Effect

•Effect of rainfall and river discharge on hatching

Results of the present investigation showed that there was no consistent effect of rainfall and river discharge on hatching of blennies. Given that

river flow and rainfall tend to affect estuarine fish recruitment as reported by Turner and Chadwick (1972), it is surprising that no patterns were seen with hatching of blennies in the Derwent River Estuary. This is especially intriguing as salinity was shown to affect settlement (chapter 4). The Derwent River Estuary is a very deep estuary, reaching over 50 m depth in places and salinity may be strongly affected by current movement (Nyan Taw, 1975). This may confound effects of river flow and rainfall on blenny hatching so that no effect was detected.

The dilution in the Derwent River Estuary by rainfall and river discharge may have little effect on the hatching of blennies as they have a broad tolerance of salinity. In a laboratory study it has been shown that salinities between 15‰ and 35‰ had no effect on embryo survival and time to hatch (Mills, 1994). The tolerance range is very wide and if these results are extrapolated to the wild, embryo survival and hatching of blennies may be independent of natural fluctuations in salinity. Thus rainfall and river discharge would be expected to have no apparent effect. The salinities recorded during sampling from the most up river site (Kangaroo Bluff) to the most oceanic site (Taroona) ranged from 13.8 to 33.7‰ at Kangaroo Bluff; 14.6 to 34.2‰ at Sandy Bay Point; and from 29.5 to 34.5‰ at Taroona which were similar to the tolerance range in salinity in the laboratory study.

•*Effect of rainfall and river discharge on larval abundance*

There appeared to be no relationship between the abundance of larvae and rainfall and river discharge at any reasonable time lags. This was not expected as there appeared to be high abundance of blenny larvae in less saline water in 1992-93 and 1993-94. The relationship within separate years between rainfall and salinity in the Derwent River Estuary was not consistent with the relationship for two years pooled. This suggests that rainfall of the magnitude recorded during the study period has relatively little effect on the blennies physical environment. Furthermore, river discharge was recorded at Meadow Bank (chapter 4, Fig. 4.1) which is far from the sampling site so relationship may become blurred. As mentioned earlier, no effect of rainfall or river discharge on hatching emerged so that rainfall and river discharge may also not affect larval abundance.

•*Effect of rainfall and river discharge on settlement*

River flows tend to affect estuarine fish as reported in striped bass, *Morone saxatilis* in the Sacramento-SanJoaquin Estuary by Turner and Chadwick (1972), and in Dove sole, *Microstomus pacificus* in Columbia River by

Hayman and Tyler (1980). Crecco and Savoy (1984) reported that year-class strength of American shad (*Alosa sapidissima*) in the Connecticut River was inversely related to river flows and total precipitation. They suggested that high river flows and low river temperatures reduce larval feeding success, survival, and ultimately year class strength. Given that river flow and rainfall tend to affect estuarine fish recruitment, it is surprising that no patterns were seen with blennies in the Derwent Estuary. This is especially intriguing as salinity was shown to affect settlement (chapter 4). As noted earlier, the Derwent River Estuary is a very deep estuary, reaching over 50 m depth in places and salinity may be strongly affected by current movement (Nyan Taw, 1975). This may also confound effects of river flow and rainfall on settlement of blennies so that no effect was detected.

Effect of Other Environmental Factors

•*Other factors affecting hatching*

Spawning/hatching of Tasmanian blennies, back-calculated from otoliths of newly settled juveniles, has been shown to vary between years (chapter 4). It is suspected that this is influenced by a wide range of biological factors. These biological factors may include food availability, egg mortality, and spawning activity which are likely to interact and affect hatching of blennies in natural habitats.

•*Eggs mortality affecting hatching rates*

Mills (1994) reported in a laboratory study that Tasmanian blennies had lower hatch rates at higher temperature (> 15°C) with many of the larvae at higher temperatures dying partially emerged from the egg. In this study, hatching of blennies in the wild may have declined due to increasing temperature. In tide pools, temperature fluctuates dramatically, depending on tide and air temperature.

Low hatching may be due to predation mortality in eggs of blennies. Demersal eggs are vulnerable to predator. Predators densities (grapsid crabs) are known to vary annually in the Derwent Estuary (Griffin, 1971).

•*Spawning activity affecting hatching*

Spawning activity may play a role in egg mortality. West (1988) reported that the male of blennies possesses two secretory glands which are continually rubbed over the egg mass. West (1988) postulated that these glands produced a secretion which protected the eggs from bacteria and

fungi. The eggs of various blenny species are very difficult to incubate without the attendant male, and suffer heavy mortality by fungus, bacterial and protozoan infection (Fishelson, 1963; Qasim, 1956; West, 1988). In the natural habitat the male parent fish constantly ventilates and cleans the eggs (West, 1988). This suggests that any change in breeding behaviour by male blennies, such as due to mortality, would result in reduced in hatching.

Other factors affecting larval abundance

•Food availability

Castro and Cowen (1991) found that duration of peak spawning season of the bay anchovy *Anchoa mitchilli* was highly correlated with larval food abundance. Interannual differences in abundance of blenny larvae may also have been related to food availability, which appeared to vary between years. Zooplankton biomass from 50 μm plankton net tows, as measured by displacement volume, was significantly lower in 1992-93 than in 1993-94 ($P < 0.0001$, ranging from 5.81 to 47.67 ml/m^3, mean = 24.85 ± 9.82 for 1992-93, versus 7.35 to 136.76 ml/m^3, mean = 54.11 ± 25.59 for 1993-94, Chamchang, unpublished data). This crude measure of prey availability appeared to affect the abundance of larvae ($P = 0.07$) although the relationship was not significant. A stronger relationship between prey items and larval abundance may have been obscured by changes in abundance of planktonic animals that were not suitable for predation by blennies. Further work on the species composition and diversity of zooplankton in 50 μm plankton net tows may provide useful biological indicators of interannual variation in abundance of blenny larvae.

•Egg mortality and fecundity affecting larval abundance

The lower larval abundance in 1992-93 compared with 1993-94 may also have been due to differing egg mortality or fecundity, although there were no data generated by the current study that could be used to test this hypothesis. However, Cook (1986) indicates a potential for interannual variation in egg production by Tasmanian blennies, which is high relative to the size of the adult. Cook (1986) reported that reproductive output was reduced on low food rations, due to both a reduction in batch size and fewer spawnings. Demersal eggs are also vulnerable to predation. As mentioned earlier, predators densities (grapsid crabs) are known to vary annually in the Derwent Estuary (Griffin, 1971). Therefore years of poor larval abundance of blennies in the present study could be due to

increased eggs predation or due to periods of low fecundity resulted from low rations.

•Predation affecting larval abundance

Changes in predator density has also been shown to affect larval abundance (Jenkins, 1986). Among the gelatinous plankton, medusae are known to be important predators of fish eggs and larvae, with feeding rates of up to 102 larvae/d (Arai and Hay, 1982; Bailey, 1984; Purcell, 1992). In the present study, medusae were occasionally encountered in high abundance; their distribution appeared to be both clumped and variable. Temporal and spatial variation in the abundance of these medusoid predators may have resulted in interannual variation in abundance of blenny larvae.

•Growth and condition of larvae

The condition and growth rate of the larvae is one source of cues to the factors that underlie variation in abundance (Hakånson, 1993). As with Tasmanian blennies, the abundance of anchovy larvae (*Engraulis mordax*) in the California Current varies greatly between years and this has been related to growth rate. Hakånson (1993) noted that although larval anchovies were more abundant in the spring of 1987 than in spring of 1986, apparent recruitment was approximately the same. He also noted that the larvae grew more slowly in 1987 and suggested that the slow growth rate may have resulted in proportionately higher mortality. This suggestion is consistent with recent overviews suggesting that predation is a major factor influencing recruitment variability (Hunter, 1981). It may be particularly important in estuaries, such as the Derwent River Estuary, as the relatively high abundance of food reduces the potential for starvation-related mortality (Houde and Lovdal, 1985; Mackenzie and Leggett, 1991). Predation may also interact with growth rates, as rapid growth rates may significantly reduce the time that younger stages are exposed to high predation rates (Bailey and Houde, 1989).

My data on the blennies is consistent with this hypothesis, as growth rates in 1993-94, the year of high abundance, was faster than in 1992-93.

•Other factors affecting settlement

Other factors which have been suggested as important determinants of juvenile density patterns are: predation; shelter availability (Sale, 1968, 1969; Low, 1971; Moran and Sale, 1977); food availability (Williams, 1979; Kingett and Choat, 1981); local densities of predators (Williams, 1980);

and post-settlement mortality (e.g. Doherty and Sale, 1986; Victor, 1986; Sale and Ferrell, 1988; etc), and larval duration variability.

•Larval duration affecting settlement

Species with very short larval life may be able to complete their development in nearshore waters and thus tend to settle without much delay (Victor, 1986). This explanation is somewhat akin to the model proposed for marine invertebrate larvae by Jackson and Strathmann (1981). This contrasts to blennies as they have long larval duration (36 to 69 days, mean = 46 days approximately), which suggests that blennies may complete their development in offshore waters (far from parent's area) resulting in delay on settlement. This may result in variability in the annual and temporal pattern of settlement of blennies.

•Habitat selection affecting settlement

As with many fishes, recruitment in blennies may be influenced by the amount of shelter (Sale, 1968, 1969; Low, 1971; Moran and Sale, 1977). This can be a passive effect on survival or else the pre-settlement stage of blennies may actively select for favourable habitat. Leis et al. (1996) demonstrated that the late pelagic stages of some species of tropical coral reef fishes are strong swimmers capable of active horizontal and vertical movement. They swim directionally, can apparently detect reef > 1 km away, and orientate relative to those reefs. In the submitted study, very few large larvae were captured with only a few postflexion larvae caught from the area with the greatest number of larvae. Consequently, any behavioural basis to settlement site selection can only be speculated.

•Fecundity affecting settlement

The physical environmental factors examined in this study could not fully explain the observed interannual differences in settlement of blennies. Some biological factor may be important such as fecundity which was not examined in this study but which may influence settlement. Richards and Lindeman (1987) suggested that recruitment to a fishery is a function of parent fecundity which can be highly variable. They also suggested that biotic and abiotic factors influencing annual fecundity can influence year class abundances as greatly as events affecting the planktonic larvae.

•Predation affecting settlement

The observed settlement rates could also be a product of different predator densities as mentioned in chapter 4. Although the predators in tide pools

have not been examined in this study, crabs are considered an important taxa for predation on settling benthic fish species (Pihl, 1990) and wide variation in the density and assemblages of shore crabs (Grapsidae) has been noted along the Derwent Estuary (Griffin, 1971). The poor years of settlement of blennies may be due to predation in the area.

The Association of Settlement with Larval Supply

Information on larval supply and settlement was collected over two years, in 1992-93 and 1993-94. As discussed previously, growth was different between years which may have influenced the extent of predation and subsequent settlement. Rate of growth may also affect the ability of larvae to find suitable habitat as populations of sessile organisms may vary seasonally in temperate regions; growth rate will affect time of settlement and thus the microenvironment encountered by settling larvae.

Results of this study indicate that blenny larval abundance provides a poor indicator of recruitment strength as high larval abundance in 1993-94 did not result in high settlement in 1993-94. The lack of a close relationship between larval abundance and settlement may have been due to the nature of the larval sample; most larvae captured were small, preflexion stage so there is potential for high mortality between this stage and settlement. Mortality of newly hatched finfish larvae is typically high and can result from starvation (e.g. Hunter, 1981) or predation (e.g. Hunter, 1981; Bailey and Houde, 1989). A far greater correlation between larval abundance and settlement is usually obtained if larvae are sampled just before settlement to give an accurate measure of larval supply (Dufour and Galzin, 1993). Many studies found a close relationship between larval supply and recruitment although most of these have been able to sample larvae which were large and immediately pre-settlement (Dufour, 1991; Milicich et al., 1992; and Thorrold et al. 1994a, 1994b, 1994c).

In the present study, adults, juveniles, and larvae were found within the Derwent River estuary which indicates that blennies spawn, hatch and recruit to the area. However, there is no information to confirm the precise location of larval development; this may occur entirely within the estuary or it may include a portion of development outside the estuary with tidal transport back to the estuary for settlement. This issue remains unclear as older larvae or pre-settlement larvae were rarely caught.

In population studies of benthic tropical reef fishes, the influx of juveniles into the benthic population is not usually measured immediately after they have settled at the end of their pelagic lives. Intervals between settlement and censuses of the surviving recruits range from a day to a week to a month or more (examples in Booth, 1991), with short intervals of one to several days being the exception rather than the rule. Daily mortality of newly settled reef fishes is typically high (Doherty and Sale, 1986; Victor, 1986; Sale and Ferrell, 1988; Meekan, 1989; Sweatman and St. John, 1990; Booth, 1991; Carr and Hixon, 1995). Hence, such mortality has the potential to cloud the relationship between recruitment and settlement and to strongly influence the sizes and dynamics of benthic populations (Eckert, 1987; Shulman and Ogdan, 1987). In this study, sampling of newly settled juveniles was done at fortnightly intervals so there is much potential for post-settlement mortality due to predation or starvation (Williams, 1979; Kingett and Choat, 1981).

Sale et al. (1984a) suggested that rates of settlement among different habitats are primarily due to a simple function of variation in the abundance of larvae competent to settle. This contrasts to the results of the present study as the region with low settlement had high larval supply. The differences in rates of settlement among tide pools appeared to be affected by factors influencing larvae at time of settlement such as habitat type.

Postflexion stage blenny larvae were rarely encountered in this study and six hypotheses are suggested to explain this. First, large larvae may be more able to avoid the plankton nets (Heath, 1992). Secondly, older larval stages may show diel vertical migratory behaviour (e.g. gobies, Miskiewiez, 1987) which may minimize their capture by daylight sampling as used in the present study. Many other studies have found greater abundance of larvae at night than during daylight hours (Clutter and Anraku, 1968; Heath, 1992). Thirdly, the collection of postflexion larvae is often unusual when sampling estuarine ichthyoplankton (Drake and Arias, 1991; Newton, 1996) as stratification occurs with older larvae more abundant near the bottom (Weinstein et al., 1980; Allen and Barker, 1990). Fourthly, larvae may develop through the later developmental stages relatively rapidly. Fifth, pre-settlement larvae may not be found within the estuary but may be transported back on flood tides to settle. Thorrold et al. (1994b) suggested that most settlement-stage reef fish at Lee Stocking Island, Bahamas moved onshore during flood tides. These immigrating larvae quickly settle to the bottom and adopt a demersal existence once

inside the estuary (Creutzberg et al., 1978; Roper, 1986). Further study of the behaviour of blennies would help establish the movement of these pre-settlement larvae.

A sixth hypothesis is that latter stage larvae may actually spend periods on the benthos. Most preflexion stage blennies were captured on ebb tides with only a few flexion stage of blennies captured on flood tides. Shanks (1995) discussed this pattern of larval movement and suggested that it may be caused by short periods of time spent on the benthos in response to tidal phase. If meroplankters spend part of the tidal cycle adjacent to the bottom, then they must have both the morphological and behavioural adaptations necessary for residence on the benthos. The morphology of many of the early larval stages of invertebrates and fish does not appear to be adapted to sitting on the bottom, and a vertical migration from the bottom into the water column is probably unlikely. However, the morphology and behaviour of many postlarvae suggest that they might be capable of sitting on the bottom (Shanks, 1995). This may be a possible explanation to account for the scarcity of postflexion stage of blennies in this study.

Further study on the relationship between larval supply and settlement of blennies is required. Sampling at night during flood tides and using appropriate gear to catch pre-settlement stage of blennies may be useful.

Overall Patterns in Tasmanian Blennies

The settlement and recruitment of blennies to tide pools are important factors in determining adult density and appeared to be chaotic in this study. The direct environmental factors assessed in this study could not explain the interannual variations in settlement. Larval supply was also a poor predictor of settlement due to lack of older larvae in sample. It appears that there may not be a single factor influencing settlement of blennies, the process may be complex and involve a series of interactions. It should not be assumed that the arrival of fish to tide pools happens in a single phase. Settlement of blennies may be independent of any environmental factors in this study; consequently, it seems to be difficult to predict interannual variations in settlement.

However, the seasonal pattern of larval abundance and settlement appeared to be able to be predicted by salinity. Larval abundance may also be influenced by other factors in a complex web: predator, preys, post-

settlement mortality. Laboratory research by Cook (1986), West (1988), and Mills (1994) and the field study presented in this thesis, suggest that important environmental factors change with development (Fig. 6.3).

Comparison with the Other Fish in Derwent Estuary

•Comparison Between Blennies and Heteroclinus spp., Estuarine Rocky Reef Fish found in the Derwent Estuary

In the Derwent Estuary, only one other study has been conducted on recruitment of fish in the order Blennioidea. This was a study by Thresher et al. (1989) on clinids (family Clinidae). Settlement variability of clinids indicates at least two important factors: episodic and irregular variation in water column production (Thresher et al., 1989) and variation in wind direction (Thresher, ms. in prep.). Wind direction, in particular, appeared to be critical in determining patterns of spatial concordance over short time scales. This contrasts to settlement of blennies that did not appear to be influenced by either of these factors. This suggests although blennies and clinids are taxonomically similar, blennies' behaviour, ecology and biology may differ from clinids (Table 6.1).

From field sampling in the present study, I observed that clinids and blennies have subtle habitat differences as tide pools with blennies tend to contain fewer clinids. Clinids prefer to live in tide pools with more sea weed (Last et al., 1983, Gunn and Thresher, 1991) while blennies prefer to live in tide pools with more rocks and crevices (Last et al, 1983, Cook, 1986) (Table 6.1).

The differences in life history and ecology of clinids and blennies are reflected in differences in settlement pattern. Gunn and Thresher (ms. in prep.) suggested that if settlement patterns differ among species, then it is reasonable to attribute such differences to parallel differences in some aspect of their ecology.

It is difficult to explain why chlorophyll-a affected the settlement of clinids but did not appeared to affect the settlement of blennies as larval feeding of clinids and blennies is similar (Table 6.1). However, in the field observation, I found that when there were more blenny larvae in plankton samples, clinids were less abundant, and vice versa, few blenny larvae were found as high abundance of clinid larvae occurred in the plankton samples (see Appendix 1). This may explain the differences in abundance in the water column and then infer to the differences in the effect of

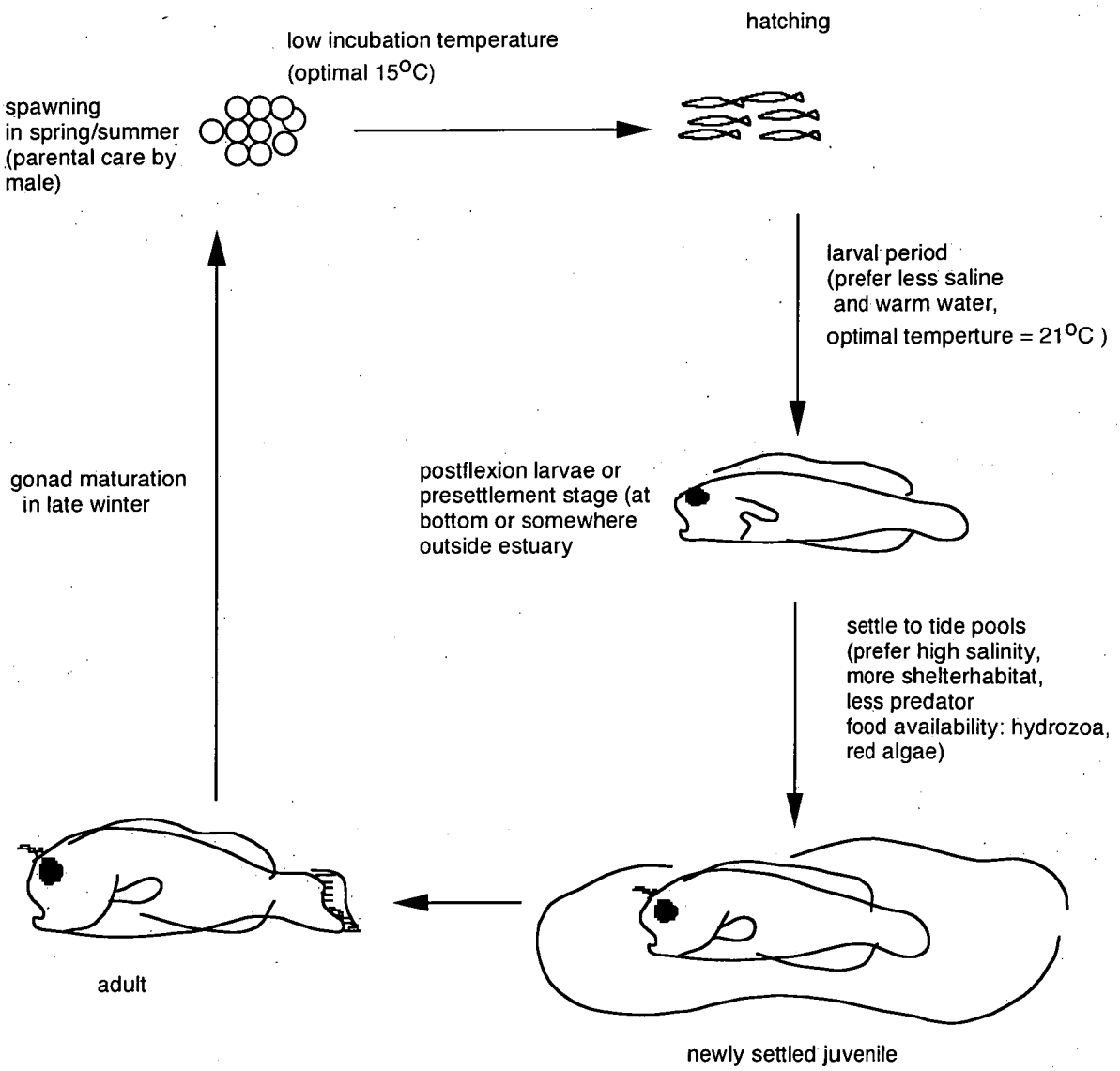

Figure 6.3 Diagram of blenny development

Table 6.1 Comparison of life history and ecology of clinids *Heteroclinus* sp. and blennies

	Clinids	Blennies
Distribution	along the temperate coasts of Western Australia, South Australia, Victoria, New South Wales and Tasmania (Last et al., 1983).	widely found in temperate and warm marine coastal habitats around the coastline of Tasmania, and along the south-east mainland Australia, from Jervis Bay (New South Wales) in the north, to Point James (South Australia) in the west (Last et al., 1983)
Diet of larvae	copepods, minute planktonic crustaceans (Thresher et al., 1989).	microzooplankton such as minute crustaceans, bivalves, copepods.
Diet of adults	ambush predators, feeding on a diverse range of benthic invertebrates and, occasionally, fishes (Last et al., 1983)	omnivorous, grazing on a range of benthic plants and animals, especially red algae and colonial hydroids, with crustaceans, molluscs and polychaetes being of lesser importance (Cook, 1986)
Habitat	near intertidal zone, generally amongst kelp or rocky reefs and seagrasses (Last et al., 1983; Gunn and Thresher, 1991)	near tide mark and in adjacent rock pools, refuge in crevices beneath stones and behind encrusting animals such as sponges and anemones (Cook, 1986).
Plankton duration	vary seasonally from 3 to 6 weeks (Thresher, 1984; Gunn and Thresher, 1991)	46 days on average with wide range from 36 to 69 days
Size at settlement	14-16 mm SL (Thresher, 1984; Gunn and Thresher, 1991).	15 - 18.5 mm SL (mean = 17.3 ± 0.87) and did not vary seasonally
Reproductive cycle	produce new broods about every 2 weeks, not lunar-entrained (Gunn and Thresher, 1991).	produce new broods about every 4 weeks and appeared to be lunar-entrained
sexual maturity	reach the minimum size for sexual maturity within a year (Gunn and Thresher, 1991).	mature in the first year (Cook, 1986)

chlorophyll-a concentration on peaks of larval abundance and subsequent settlement due to the occurrence at the different time and space. Further study on chlorophyll-a concentration affecting larval abundance and settlement is required to compare these two species.

Comparison with Other Fish from Around the World

Recruitment of demersal coral reef fishes is well documented with relative few studies conducted on temperate fish species. Recent work on many coral reef fish has shown that juvenile recruitment is highly variable both across space and between years (Luckhurst and Luckhurst, 1977; Russell et al., 1977; Talbot et al, 1978; Williams, 1980, 1983; Williams and Sale, 1981). Temporal variation ranges from seasonal patterns to lunar, semilunar and episodic peaks within seasons (Doherty and Williams, 1988). In the present study, there appeared to be seasonal pattern to lunar phase on episodic peaks of larval abundance (on new moon) and settlement of blennies (on waxing halfmoon). This is similar to some of other blenniid species in coral reefs. There is no information specifically dealing with possible lunar rhythms in the spawning of other blenniid species. Thresher (1984) cited work of Wickler (1965) who found that blenniid *Ecsenius bicolor* spawned in captivity almost exactly at two-week intervals, which may indicate a semi-lunar rhythm. Spawning of *Exallias brevis* in Hawaii occurs at three- to four-day intervals and is not conspicuously synchronized to any specific lunar periodicity (B. Carlson, pers. comm. cited by Thresher, 1984). Spawning activity for several species of blennies at One Tree Island, Great Barrier Reef, was conspicuously periodic and widely synchronized (Thresher, 1984). Field observations by Thresher (1984) indicate that newly laid eggs and spawning behaviour invariably occurred a week or so preceding new and full moons.

Coral reef fishes have provided a number of examples of recruitment-limited populations. These populations have the characteristics of open non-equilibrial systems in which fluctuating recruitments from larval sources appear to be the major variable driving the densities of older fishes (see review in Doherty, 1987). In this study, larval supply of blennies appeared to be not a useful predictor due to lack of older larvae included in samples. However, the fluctuating recruitments from larval sources may be a major variable driving the densities of blennies but more research will be required to fully evaluate any links.

Summary

- Phytoplankton production (chlorophyll-a concentration) appeared to have no effect on hatching, the abundance of larvae and settlement variability.
- Tidal cycle, rainfall, and river discharge appeared to have little effect on hatching, larval abundance, or settlement variability.
- Lunar cycle appeared to influence hatching, seasonal larval abundance (highest number on new moon), and settlement (greatest number on waning half moon).
- Wind appeared to affect the larval abundance at a lag of 5 d but did not appear to affect settlement when assessed for either daily or weekly lags.
- There was a strong trend of high larval abundance and settlement when temperature was high.
- Salinity is a useful predictor of the abundance and distribution of larvae and settlement. Blenny larvae preferred less saline water while newly settled juveniles preferred higher salinity.

Suggested Further Studies

- The ratio of RNA/DNA provides a measure of larval condition as it is influenced by the extent of protein synthesis (Raae et al., 1988). This measure of condition has been used in studies of larval fish to understand patterns of variability in settlement; larvae in good condition tend to have a higher RNA/DNA ratio than those in poorer condition (e.g. Robinson and Ware, 1988; Clemmensen, 1993). Martin and Wright (1987) reported that the ratio can respond to changes in environmental conditions within 1-3 days and it has been used to find a measure of instantaneous growth in the field (Buckley, 1981; Clarke et al., 1989). It may be used in further study of blennies to augment analysis of the effect of condition, which was only inferred indirectly in this study by chlorophyll level, total plankton displacement, and growth rate.
- Further work on feeding of blennies is required as information on species compositon and diversity of zooplankton in the environment may provide useful biological indicators of interannual and seasonal variation in abundance of blenny larvae.
- Further study on fecundity of blennies may be useful to account for the difference in larval abundance and settlement between years.

- Further study on predators and prey items in the water column and in tide pools may account for the interannual, seasonal, and spatial variation in larval abundance and settlement.
- Further study on behaviour of larvae and newly settled juveniles during tidal cycle and during lunar phases is required to explain their vertical migration patterns and settling preferences.
- Further investigation to determine the location of postflexion larvae of blennies is required to test two hypotheses. First, postflexion larvae may be dispersed away from the parent's area by currents and then actively swim or be driven onshore to settle into suitable tide pools. Secondly, postflexion larvae may develop somewhere outside the estuary and return to the estuary to settle. Sampling at night during flood tides and using appropriate gear to catch pre-settlement stage of blennies may be useful. Postflexion or pre-settlement stage larvae (larval supply) are useful to predict settlement between years. Tagging larval movement by marking the otoliths of larvae with oxytetracycline may be useful.
- Further study on the effect of interaction between lunar phase and temperature on larval abundance may be useful to account for the seasonal pattern of larval abundance.
- Further investigation on controlled laboratory experiments should be undertaken to account for the effect of chlorophyll-a concentration on larval survival and subsequent settlement.

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Appendix 1 a Species composition of fish larvae collected during October 1992 to February 1993 in the Derwent Estuary (Taroona sampling site) (S.F.= surface sampling, S.S.F.= subsurface sampling, ns= no sampling). Values given for each family and species correspond to the non-adjusted numbers of larvae caught during the study.

DATE / FAMILY	12 October 1992			19 October 1992			26 October 1992			2 November 1992		
	Number of fish larvae											
	S.F.	S.S.F.	**Total**	S.F.	S.S.F.	**Total**	S.F.	S.S.F.	**Total**	S.F.	S.S.F.	**Total**
Engraulidae		ns			ns			ns		17	ns	**17**
Galaxiidae		ns		1	ns	**1**		ns			ns	
Syngnathidae		ns			ns			ns			ns	
Pegasidae		ns			ns			ns			ns	
Atherinidae		ns			ns			ns			ns	
Scorpaenidae	1	ns	**1**	5	ns	**5**		ns		4	ns	**4**
Triglidae		ns			ns			ns			ns	
Platycephalidae		ns			ns			ns			ns	
Sillaginidae		ns			ns		2	ns	**2**		ns	
Pempheridae		ns			ns			ns			ns	
Latridae		ns		1	ns	**1**		ns			ns	
Mugilidae		ns			ns			ns			ns	
Sphyraenidae	1	ns	**1**		ns			ns			ns	
Labridae		ns		2	ns	**2**		ns			ns	
Tripterygiidae		ns			ns			ns			ns	
Clinidae	1	ns	**1**	10	ns	**10**	12	ns	**12**	5	ns	**5**
Blenniidae		ns			ns			ns		2	ns	**2**
Gobiidae		ns		1	ns	**1**		ns			ns	
Gobiesocidae		ns			ns			ns		1	ns	**1**
Pleuronectidae	2	ns	**2**	7	ns	**7**	1	ns	**1**	1	ns	**1**
Monacanthidae		ns			ns			ns			ns	
Tetraodontidae		ns			ns			ns			ns	
Tripterygiidae/Clinidae		ns			ns			ns			ns	
Unidentified		ns		1	ns	**1**		ns			ns	
Yolk-sac larvae		ns		4	ns	**4**		ns		1	ns	**1**
Total	**5**	**ns**	**5**	**32**	**ns**	**32**	**15**	**ns**	**15**	**31**	**ns**	**31**

Appendix 1a (continued)

DATE / FAMILY	16 November 1992			24 November 1992			30 November 1992			7 December 1992		
	Number of fish larvae											
	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total
Engraulidae	11	90	**101**	101	325	**426**	3	90	**93**	564	191	**755**
Galaxiidae												
Syngnathidae					1	**1**						
Pegasidae												
Atherinidae				69		**69**	12		**12**	19		**19**
Scorpaenidae	7		**7**	8	1	**9**				6		**6**
Triglidae		2	**2**		20	**20**		2	**2**		5	**5**
Platycephalidae		2	**2**		46	**46**					6	**6**
Sillaginidae					1	**1**					8	**8**
Pempheridae												
Latridae												
Mugilidae												
Sphyraenidae												
Labridae	1		**1**									
Tripterygiidae												
Clinidae	1		**1**	2		**2**	1		**1**	6		**6**
Blenniidae					1	**1**				8	7	**15**
Gobiidae				2	4	**6**	2		**2**	3	5	**8**
Gobiesocidae								1	**1**		5	**5**
Pleuronectidae												
Monacanthidae				5	9	**14**						
Tetraodontidae												
Tripterygiidae/Clinidae										2	5	**7**
Unidentified	2		**2**	2		**2**				6		**6**
Yolk-sac larvae										12	2	**14**
Total	**22**	**94**	**116**	**189**	**408**	**597**	**18**	**93**	**111**	**626**	**234**	**860**

Appendix 1a (continued)

DATE / FAMILY	15 December 1992			21 December 1992			30 December 1992			5 January 1993		
	Number of fish larvae											
	S.F.	S.S.F.	**Total**	S.F.	S.S.F.	**Total**	S.F.	S.S.F.	**Total**	S.F.	S.S.F.	**Total**
Engraulidae	5	109	**114**		45	**45**	2	157	**159**	117	74	**191**
Galaxiidae					1	**1**						
Syngnathidae												
Pegasidae												
Atherinidae	7		**7**	3		**3**	3		**3**			
Scorpaenidae								2	**2**	2		**2**
Triglidae		2	**2**		8	**8**		5	**5**		1	**1**
Platycephalidae												
Sillaginidae		3	**3**					6	**6**	2	5	**7**
Pempheridae												
Latridae												
Mugilidae												
Sphyraenidae												
Labridae		1	**1**									
Tripterygiidae				1		**1**	1		**1**			
Clinidae												
Blenniidae	3		**3**		1	**1**	1	1	**2**		1	**1**
Gobiidae		2	**2**	1	5	**6**		3	**3**		3	**3**
Gobiesocidae					2	**2**						
Pleuronectidae												
Monacanthidae	2	2	**4**				2	2	**4**		3	**3**
Tetraodontidae												
Tripterygiidae/Clinidae	1		**1**		3	**3**						
Unidentified	1		**1**	2	1	**3**		1	**1**			
Yolk-sac larvae	17	2	**19**	2	2	**4**	9	1	**10**	6		**6**
Total	**36**	**121**	**157**	**9**	**66**	**75**	**18**	**178**	**196**	**127**	**87**	**214**

Appendix 1a (continued)

DATE / FAMILY	11 January 1993			18 January 1993			25 January 1993			3 February 1993					
	Number of fish larvae														
	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total	*Total*	*%Total catch*	*Rank*
Engraulidae	438	375	**813**		27	**27**	49	44	**93**		36	**36**	***2870***	***81.69***	***1***
Galaxiidae											1	**1**	***4***	***0.11***	***16***
Syngnathidae					1	**1**							***2***	***0.05***	***18***
Pegasidae								1	**1**				***1***	***0.03***	***20***
Atherinidae	1		**1**										***114***	***3.24***	***2***
Scorpaenidae	1		**1**				1		**1**	2		**2**	***40***	***1.14***	***8***
Triglidae		1	**1**								6	**6**	***52***	***1.48***	***5***
Platycephalidae													***54***	***1.54***	***4***
Sillaginidae	1		**1**								3	**3**	***31***	***0.88***	***10***
Pempheridae	1		**1**										***1***	***0.03***	***20***
Latridae													***1***	***0.03***	***20***
Mugilidae								1	**1**		1	**1**	***2***	***0.05***	***18***
Sphyraenidae													***1***	***0.03***	***20***
Labridae													***4***	***0.11***	***16***
Tripterygiidae	3		**3**	2		**2**	1		**1**				***8***	***0.23***	***14***
Clinidae													***38***	***1.08***	***9***
Blenniidae	2	3	**5**		1	**1**	4	6	**10**	1	4	**5**	***46***	***1.31***	***6***
Gobiidae	6	2	**8**	1	11	**12**		1	**1**		9	**9**	***61***	***1.73***	***3***
Gobiesocidae	1	1	**2**										***11***	***0.31***	***11***
Pleuronectidae													***11***	***0.31***	***11***
Monacanthidae								6	**6**	1	10	**11**	***42***	***1.19***	***7***
Tetraodontidae		1	**1**		1	**1**	3		**3**		3	**3**	***8***	***0.23***	***14***
Tripterygiidae/Clinidae													***11***	***0.31***	***11***
Unidentified	4		**4**	5		**5**				3		**3**	***28***	***0.78***	
Yolk-sac larvae	4	1	**5**	4		**4**	4	1	**5**				***72***	***2.05***	
Total	**462**	**384**	**846**	**12**	**41**	**53**	**62**	**60**	**122**	**7**	**76**	**83**	***3513***		

Appendix 1 b Species composition of fish larvae collected during November 1993 to February 1994 in the Derwent Estuary (Taroona sampling site) (S.F.= surface sampling, S.S.F.= subsurface sampling, ns= no sampling). Values given for each family and species correspond to the non-adjusted numbers of larvae caught during the study.

DATE / FAMILY	5 November 1993			12 November 1993			19 November 1993			26 November 1993		
	Number of fish larvae											
	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total
Engraulidae	81	15	**96**	555	206	**761**	259	62	**321**	9	148	**157**
Ophichthidae												
Galaxiidae												
Moridae								1	**1**			
Syngnathidae				1		**1**		1	**1**			
Pegasidae	1		**1**					2	**2**			
Atherinidae	10		**10**	8		**8**	16	3	**19**	8		**8**
Scorpaenidae	2		**2**	2		**2**						
Triglidae				1		**1**	1	1	**2**			
Platycephalidae	1		**1**									
Sillaginidae							1		**1**			
Carangidae												
Pempheridae												
Mugilidae												
Labridae												
Creediidae												
Leptoscopidae										1		**1**
Tripterygiidae	5		**5**				43	2	**45**	17		**17**
Clinidae	8		**8**	9		**9**	17	5	**22**	25		**25**
Blenniidae	10		**10**	1	2	**3**	5	4	**9**	9		**9**
Gobiidae	8		**8**	19	12	**31**	139	44	**183**	28	6	**34**
Gobiesocidae				3	1	**4**	62	8	**70**			
Callionymidae												
Bothidae												
Pleuronectidae		2	**2**				1		**1**			
Monacanthidae	16	1	**17**				1		**1**	5		**5**
Tripterygiidae/Clinidae	1		**1**									
Cepolidae?												
Unidentified	3	3	**6**	5	4	**9**	24	4	**28**	8	11	**19**
Yolk-sac larvae				2	no	**2**	6		**6**	3		**3**
Total	**146**	**21**	**167**	**606**	**225**	**831**	**575**	**137**	**712**	**113**	**165**	**278**

Appendix 1b (continued)

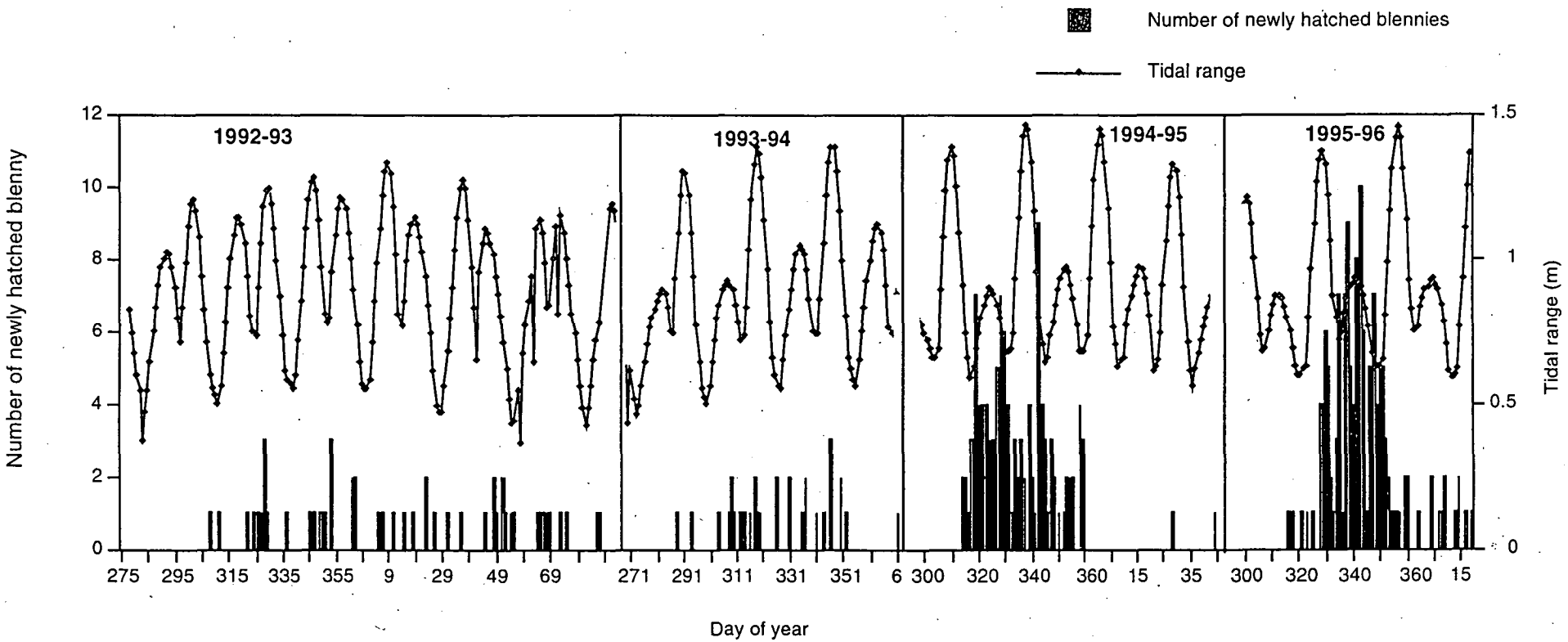
DATE / FAMILY	6 December 1993			10 December 1993			17 December 1993			24 December 1993		
	Number of fish larvae											
	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total
Engraulidae	13	89	**102**	47	338	**385**	937	509	**1446**	478	363	**841**
Ophichthidae												
Galaxiidae											2	**2**
Moridae												
Syngnathidae					1	**1**				1		**1**
Pegasidae							2		**2**		1	**1**
Atherinidae				4		**4**	23		**23**	16		**16**
Scorpaenidae		2	**2**		2	**2**						
Triglidae		3	**3**		2	**2**		1	**1**	1		**1**
Platycephalidae					2	**2**						
Sillaginidae				3	12	**15**	5	3	**8**		19	**19**
Carangidae												
Pempheridae												
Mugilidae		1	**1**							4	1	**5**
Labridae							1	1	**2**		1	**1**
Creediidae												
Leptoscopidae		1	**1**					1	**1**		1	**1**
Tripterygiidae	2		**2**	8	4	**12**	11	3	**14**			
Clinidae	2	1	**3**	45	9	**54**	16	1	**17**	21	1	**22**
Blenniidae	7	3	**10**	26	31	**57**	18	2	**20**	3	4	**7**
Gobiidae		23	**23**	15	135	**150**	13	10	**23**	4	30	**34**
Gobiesocidae							2	1	**3**		1	**1**
Callionymidae								1	**1**			
Bothidae												
Pleuronectidae							3	1	**4**		2	**2**
Monacanthidae				1	5	**6**	3	1	**4**	4	5	**9**
Tripterygiidae/Clinidae				2	3	**5**						
Cepolidae?					1	**1**						
Unidentified	1	1	**2**	9	21	**30**	21	6	**27**	27	9	**36**
Yolk-sac larvae	1		**1**	1	2	**3**	15	5	**20**	2		**2**
Total	**26**	**124**	**150**	**161**	**568**	**729**	**1070**	**546**	**1616**	**561**	**440**	**1001**

Appendix 1b (continued)

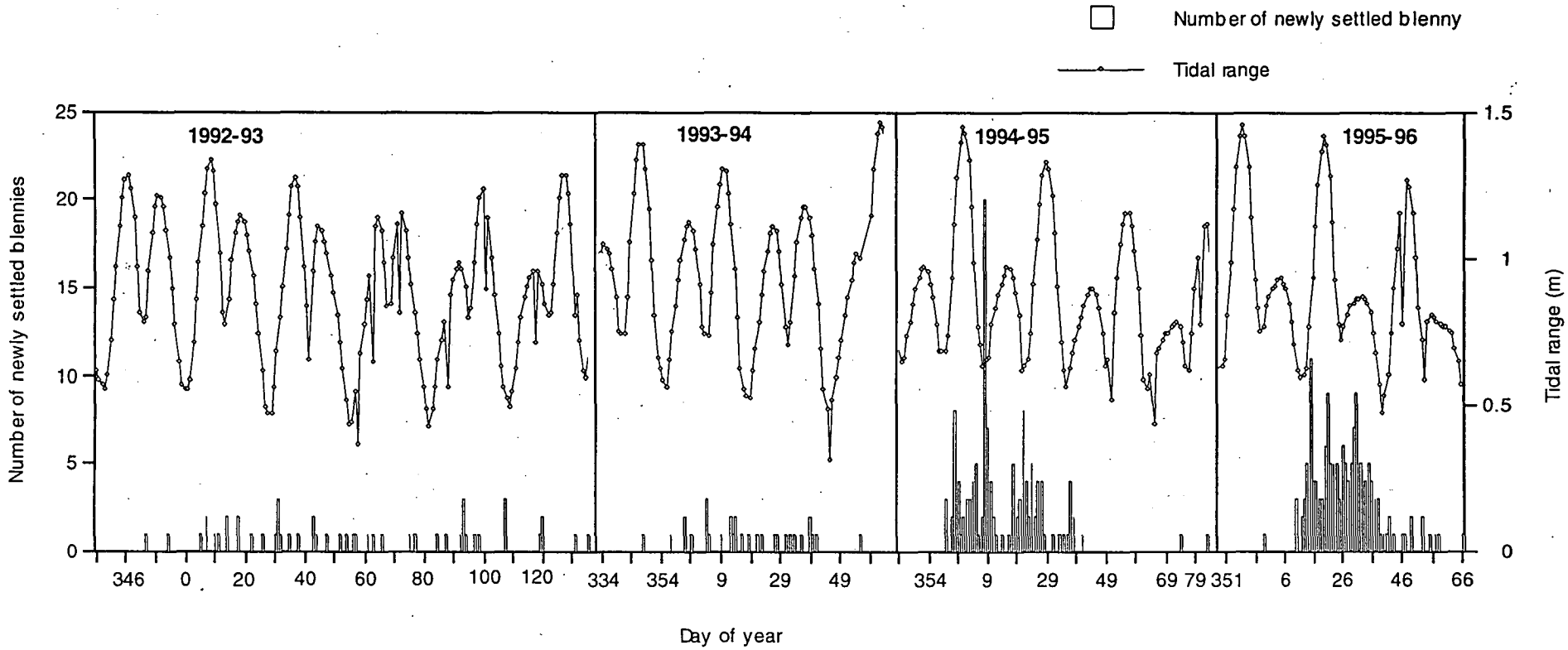
DATE / FAMILY	7 January 1994			14 January 94			21 January 94			31 January 1994		
	Number of fish larvae											
	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total
Engraulidae	1385	788	**2173**	365	169	**534**	215	377	**592**	335	57	**392**
Ophichthidae	1		**1**									
Galaxiidae												
Moridae								1	**1**			
Syngnathidae	1		**1**	1		**1**				1	1	**2**
Pegasidae	3		**3**							1	1	**2**
Atherinidae				27	4	**31**	13		**13**			
Scorpaenidae	3		**3**		1	**1**	4	5	**9**			
Triglidae	3	5	**8**		1	**1**	1		**1**	1	1	**2**
Platycephalidae											1	**1**
Sillaginidae	10	7	**17**	4	1	**5**	10	3	**13**	5	1	**6**
Carangidae												
Pempheridae	1		**1**				4		**4**			
Mugilidae	79	79	**158**	1	1	**2**	31	7	**38**			
Labridae	1		**1**					1	**1**			
Creediidae				1		**1**	2		**2**			
Leptoscopidae	3		**3**	1		**1**	1		**1**			
Tripterygiidae	9		**9**	12	9	**21**	4		**4**	7	1	**8**
Clinidae	1	2	**3**	3	1	**4**				3	1	**4**
Blenniidae	7	1	**8**	34	6	**40**	9		**9**	1	2	**3**
Gobiidae	77	67	**144**	12	3	**15**	4	17	**21**	49	4	**53**
Gobiesocidae										2		**2**
Callionymidae												
Bothidae												
Pleuronectidae	1		**1**	1		**1**	2	6	**8**	5	1	**6**
Monacanthidae	7		**7**				3	3	**6**			
Tripterygiidae/Clinidae				4		**4**						
Cepolidae?								1	**1**			
Unidentified	132	12	**144**	24	4	**28**	33	2	**35**	18	4	**22**
Yolk-sac larvae		7	**7**				2		**2**	2		**2**
Total	**1724**	**968**	**2692**	**490**	**200**	**690**	**338**	**423**	**761**	**430**	**75**	**505**

Appendix 1b (continued)

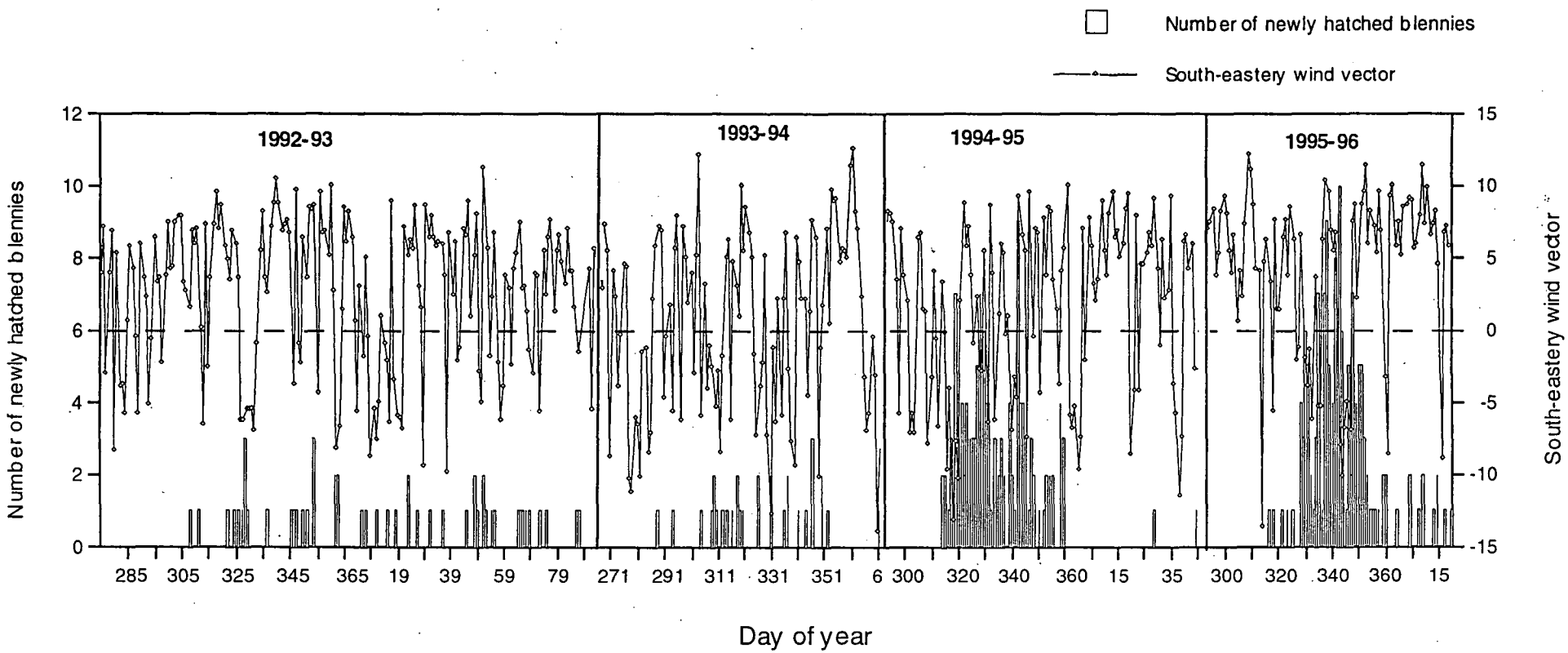
DATE / FAMILY	4 February 1994			11 February 1994			18 February 1994					
	Number of fish larvae											
	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total	S.F.	S.S.F.	Total	*Total catch*	*%Total catch*	*Rank*
Engraulidae	154	899	**1053**	10	36	**46**	511	ns	**511**	***9410***	***77.80***	***1***
Ophichthidae										***1***	***0.01***	***25***
Galaxiidae										***2***	***0.01***	***22***
Moridae										***2***	***0.01***	***22***
Syngnathidae		2	**2**		2	**2**				***12***	***0.10***	***15***
Pegasidae	2		**2**		2	**2**				***15***	***0.12***	***14***
Atherinidae										***132***	***1.09***	***8***
Scorpaenidae					1	**1**	4	ns	**4**	***26***	***0.21***	***12***
Triglidae		1	**1**		3	**3**	1	ns	**1**	***27***	***0.22***	***11***
Platycephalidae	1	no	**1**							***5***	***0.04***	***19***
Sillaginidae	1	21	**22**	3	6	**9**	27	ns	**27**	***142***	***1.17***	***7***
Carangidae							1	ns	**1**	***1***	***0.01***	***25***
Pempheridae					2	**2**				***7***	***0.06***	***17***
Mugilidae				6	16	**22**	18	ns	**18**	***244***	***2.02***	***3***
Labridae					1	**1**				***6***	***0.05***	***18***
Creediidae							1	ns	**1**	***4***	***0.03***	***20***
Leptoscopidae	n	2	**2**		1	**1**				***12***	***0.10***	***17***
Tripterygiidae	4		**4**	72	4	**76**	2	ns	**2**	***219***	***1.81***	***4***
Clinidae	1		**1**	1		**1**				***173***	***1.43***	***6***
Blenniidae	4		**4**	13	2	**15**	3	ns	**3**	***207***	***1.71***	***5***
Gobiidae	6	9	**15**	1	2	**3**				***737***	***6.09***	***2***
Gobiesocidae		2	**2**				3	ns	**3**	***85***	***0.70***	***9***
Callionymidae										***1***	***0.01***	***25***
Bothidae							3	ns	**3**	***3***	***0.02***	***21***
Pleuronectidae										***25***	***0.21***	***13***
Monacanthidae	5	5	**10**	1	8	**9**	3	ns	**3**	***77***	***0.64***	***10***
Tripterygiidae/Clinidae										***10***	***0.08***	***16***
Cepolidae?										***2***	***0.01***	***22***
Unidentified	10	9	**19**	8	5	**13**	32	ns	**32**	***450***	***3.72***	
Yolk-sac larvae				1		**1**	9	ns	**9**	***58***	***0.48***	
Total	**188**	**950**	**1138**	**116**	**91**	**207**	**618**	**ns**	**618**	***12095***		



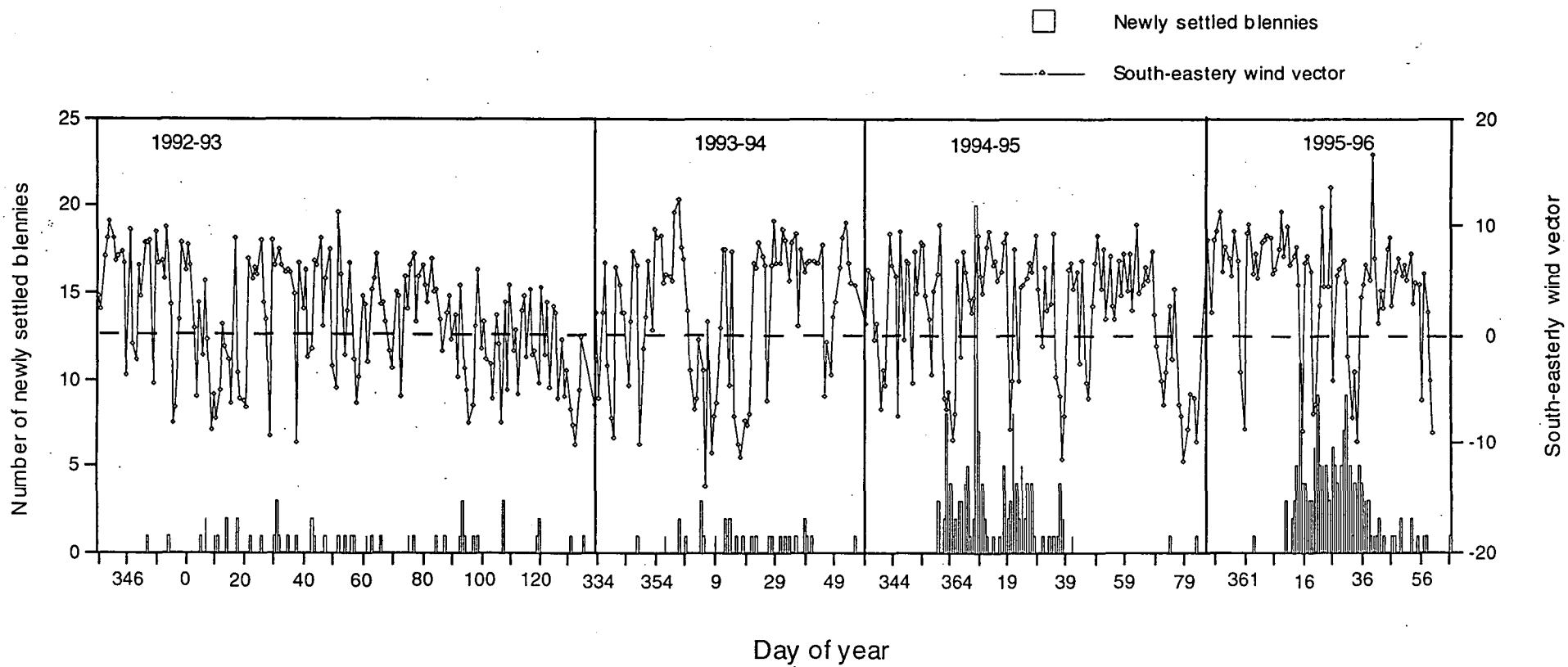
Appendix 2 Daily pattern of tidal cycle in relation to number of newly hatched blennies during spring/summer from 1992-93 to 1995-96. Bar charts show number of newly hatched blennies; line charts show daily tidal cycle



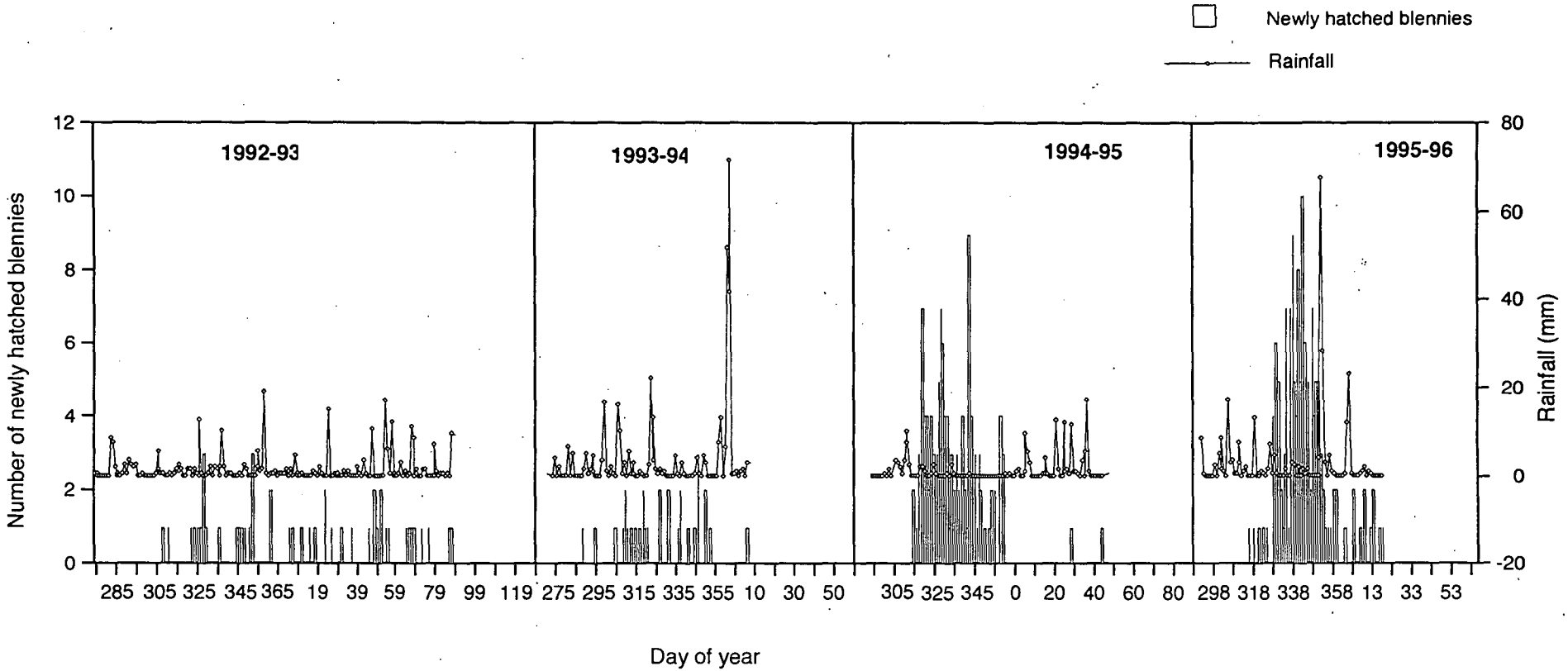
Appendix 3. Daily pattern of tidal cycle in relation to number of newly settled blennies during spring/summer from 1992-93 to 1995-96. Bar charts show number of newly settled blennies; line charts show daily tidal cycle



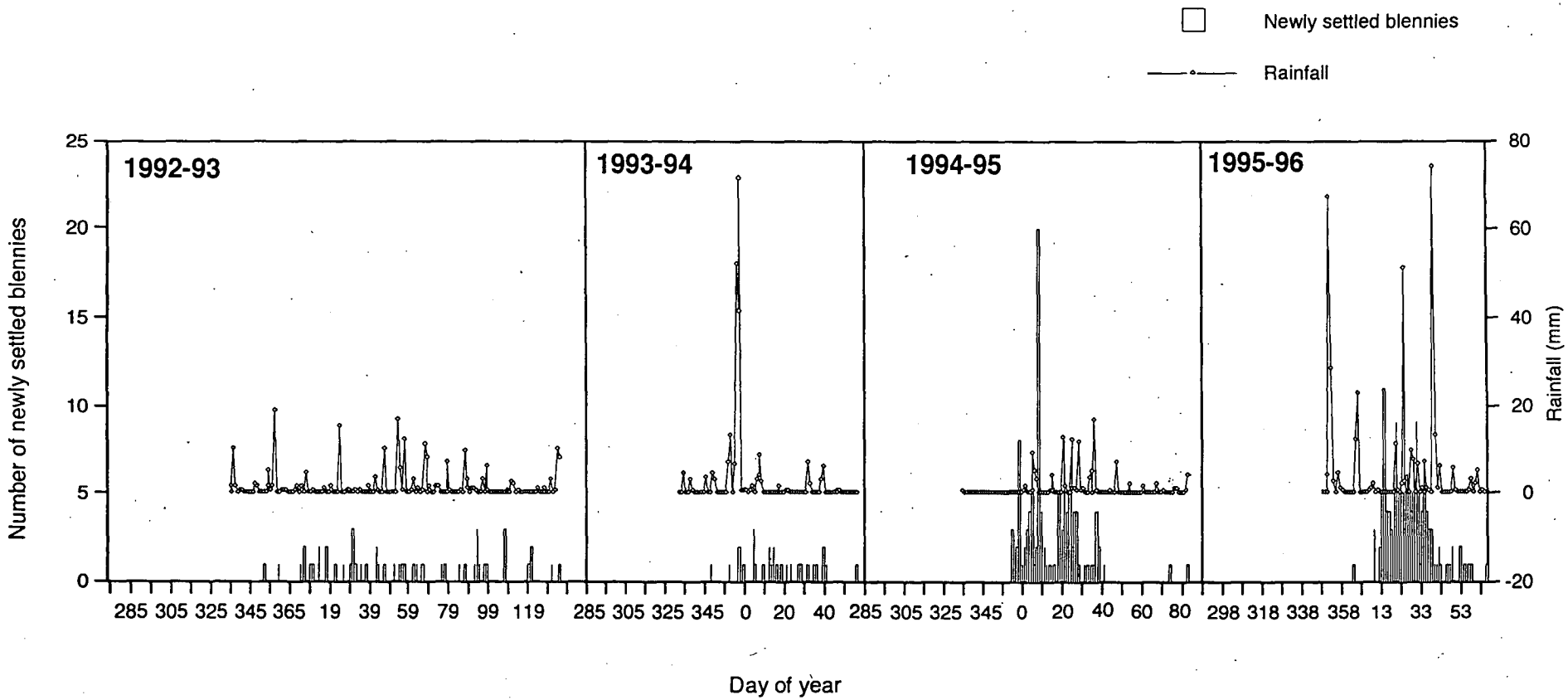
Appendix 4. Daily pattern of south-easterly wind vector in relation to number of newly hatched blennies during spring/summer from 1992-93 to 1995-96. Bar charts show number of newly hatched blennies; line charts show south-easterly wind vector.



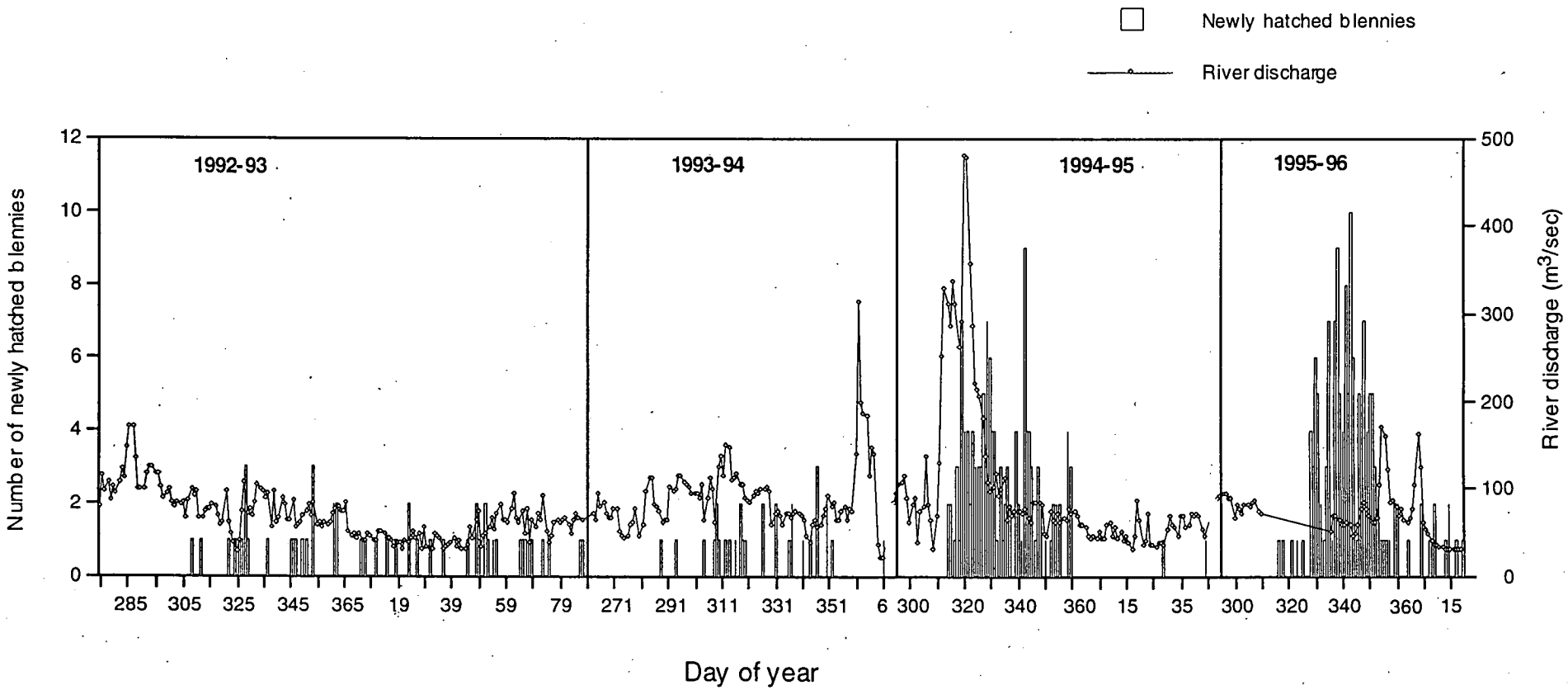
Appendix 5. Daily pattern of south-easterly wind vector in relation to number of newly settled blennies during spring/summer from 1992-93 to 1995-96. Bar charts show number of newly settled blennies; line charts show daily south-easterly wind vector



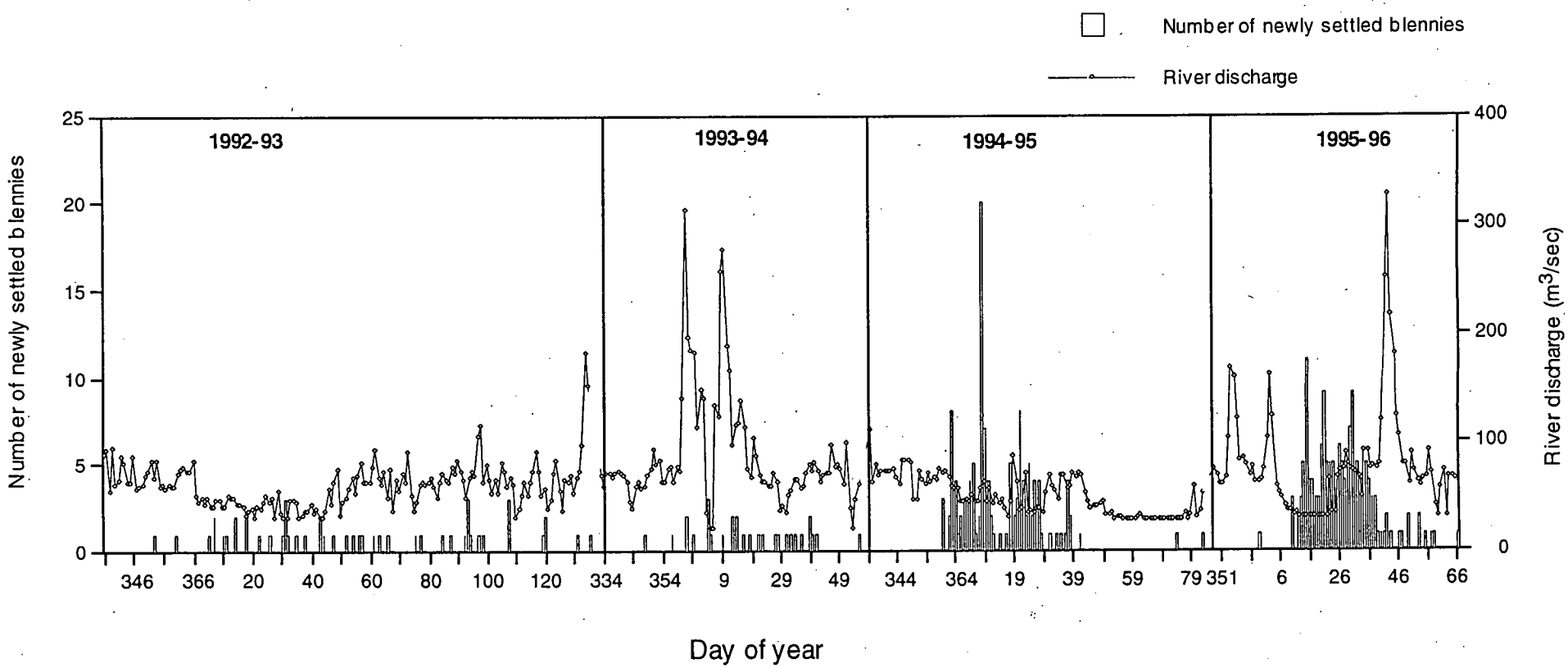
Appendix 6. Pattern of daily hatching dates in relation to daily rainfall during spring/summer 1992-93 to 1995-96 in Derwent River Estuary



Appendix 7. Daily pattern of rainfall in relation to number of newly settled blenies during spring/summer from 1992-93 to 1995-96. Bar charts show number of newly settled blennies; line charts show daily rainfall.



Appendix 8. Daily pattern of river discharge in relation to number of newly hatched blennies during spring/summer from 1992-93 to 1995-96. Bar charts show number of newly hatched blennies; line charts show daily river discharge.



Appendix 9. Daily pattern of river discharge in relation to number of newly settled blennies during spring/summer from 1992-93 to 1995-96. Bar charts show number of newly settled blennies; line charts show daily river discharge.